Analytical Methods for Studies and Experiments on "Transforming the Force"

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DOCUMENTED BRIEFING

Analytical Methods for Studies and Experiments on "Transforming the Force"

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Prepared for the
Office of the Secretary of Defense

RAND National Defense Research Institute

Preface

This documented briefing describes interim progress on a project concerned with "transforming U.S. forces" to reflect what is often called the revolution in military affairs. After background review describing a broad transformation strategy, we discuss and illustrate how analysis supported by models and simulations (including gaming) can supplement and guide empirical work such as joint experiments on new operational concepts. A first version of the briefing was presented to the advisory board of RAND's National Defense Research Institute (NDRI) on October 28, 1998. NDRI is a federally funded research and development center (FFRDC) that serves the Office of the Secretary of Defense, the Joint Staff, Defense Agencies, and Unified Commands. Comments on the work are welcome and should be addressed to the principal author at RAND in Santa Monica, CA (310-451-6912 or Paul_Davis@rand.org).

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Summary

Background

Motivated by both opportunities and necessity, the Department of Defense (DoD) plans to transform the force over the years ahead. It will do so by exploiting modern technology and new operational concepts, and by making related organizational changes. The opportunity here is that U.S. forces can greatly increase their capabilities and, in some cases, reduce costs at the same time. However, major changes will also be *necessary*, to mitigate difficulties posed by even mid-level rogue states such as Iraq or North Korea. These difficulties include short-warning attacks and other so-called "asymmetric" strategies involving mass-casualty weapons, missiles, mines, high-lethality conventional weapons, exploitation of urban sprawl and innocent civilians, and coercion of regional states to reduce U.S. access.

Despite the need for transformation, it will be extremely difficult to make the changes contemplated by *Joint Vision 2010* (Joint Staff, 1996) and the Quadrennial Defense Review (Cohen, 1997). This briefing describes progress in a project to assist the DoD in thinking about (1) transformation strategy generally and (2) ways in which analysis can guide and supplement research and experimentation. Our emphasis is on joint capabilities at the operational level.

Recommendations for Transformation Strategy

In the first part of this briefing, we review the project's work on broad transformation strategy. Early in 1998 we recommended that the Secretary of Defense establish key *operational challenges* to be met with future forces. The challenges—e.g., being able to halt an invading army *quickly* and, after a halt, conducting a decisive counteroffensive without first taking many months to build forces—would be important, but quite difficult. They would be forcing functions of change. Addressing the challenges would lead to capabilities for building-block military operations useful in diverse future circumstances. Meeting these stressful challenges would require changes often discussed under the fuzzy rubric of the revolution in military affairs (RMA).

We observed that managing transformation would require artful synthesis of top-down and bottom-up activities. Ideally, high DoD officials such as an Assistant Secretary and the Vice Chairman (or a new Deputy Chairman) would focus almost exclusively on overseeing transformation activities. These leaders would work with the Commander in Chief of the U.S. Atlantic Command (CINC USACOM) to decompose the operational challenges and identify subordinate challenges and responsibilities consistent with statutory service- and unified-commander missions. The goal here would be functional/technical and operational *integration*—rather than mere coordination—of capabilities for future joint operations. Halting an invading army quickly, for example, may require integrated execution, within days and at a theater level, of many building-block operations. These might include: (1) establishing C^2 and C^4ISR; (2) establishing air and missile defense; (3) securing bases (perhaps with forcible entry) and sea-lanes; (4) suppressing air defenses; (5) attacking armored forces with long-range fires; (6) enhancing the effectiveness of defending allies on the ground; and (7) inserting ground maneuver forces, perhaps to disrupt rear areas. Within the Pentagon, a goal would be to support transformation issues within the acquisition process and the Planning, Programming, and Budgeting System (PPBS) process.

In reviewing the situation in early 1999, we note that many related processes are now in place as the result of DoD's decisions last year. However, the processes are weakened by divided responsibilities, the multiple missions that burden some of the principals, and the inherent limitations of committee action. *Joint Vision 2010* is a strong vision document, but efforts to implement it do not provide adequate guidance for the services, USACOM, and others. More top-down effort is needed.

Despite recommending a stronger top-down component for challenge setting and defining the architecture for a system of future joint capabilities, we continue to stress that innovation should largely come from the services—who are vigorously seeking to transform themselves as part of their continuing statutory responsibilities—and from CINC USACOM and some of the other CINCs and subordinate commanders acting explicitly as joint *change agents*. This role for joint commanders is feasible only because near-term aspects of transformation can directly assist them with near-term military problems, while also setting the stage for many longer-term developments. To summarize, we recommend the basic rule that demands (or needs) should be specified sharply from above (with insights from below), but innovative problem solving should be both distributed and bottom up.

Fortunately, many innovations are already visible as, for example, the Air Force experiments with air expeditionary forces (AEFs), the Marines experiment with new doctrine for urban warfare, the Navy pursues network-centric missile-defense and strike options, and the Army studies a new rapidly deployable strike force. Concepts abound, and all of the services are at least attempting to conduct their activities "in a joint context"—i.e., taking into account, to a greater or lesser degree, that they will be operating with the other services rather than unilaterally. The problems we see are not at this level but, again, at the levels of problem definition, architecture, and integration. Although good concepts and lists of desired functional capabilities exist, they are generally not well defined or well connected. Our recommendations here are as follows:

- The Department of Defense should focus management attention more on meeting *operational* challenges (e.g., the early halt and all the subordinate operations that implies) in diverse circumstances, than on addressing open-ended *functional* challenges (e.g., building systems for general information dominance).
- Such a focus would enforce an output-oriented system view, in which success of an entire military operation under stressful dynamic circumstances (output) is seen to depend on the adaptive and facile integration of many component operations. It would also define more sharply requirements for building-block operational capabilities, adaptive integration capability, and cross-cutting functional capabilities.

Research and Experimentation

The remainder of our briefing describes recent work on how analysis can help guide and supplement research, including experimentation, on future joint military capabilities. A central tenet is that achieving advanced operational capabilities will require far more than the joint experiments commonly discussed by DoD, Congress, and others. A research base is needed to understand the phenomenology of future operations. Further, large-scale joint field experiments—although enormously valuable—will necessarily be both sparse and constrained. Success in transformation will therefore require smaller-scale experiments and extensive gaming and analysis. The DoD should—for each major warfare area affecting the operational challenges—ensure development of analytic architectures, supported by model and simulation *families*, to permit gaming and analysis at many levels of resolution and from many perspectives. The tools needed will be quite different from those the DoD has typically used in force-planning studies. Human gaming and human-in-the-loop simulation will be crucial for innovation, as will modern "agent-based simulations" (i.e., simulations with submodels making human-like adaptive

decisions) that can represent newly conceived adaptive tactics and doctrine. Old-fashioned "scripted models" (with no such adaptive decisionmaking) will—with good reason—continue to antagonize warriors, who often find little value in the models they see.

Another key feature of transformation-related analysis should be the routine study of massive uncertainty, so that the services and joint commanders can reduce risks—in part by developing doctrine that deals effectively with uncertainty. Such a thrust will require radical changes in the questions asked by decisionmakers and the practice of analysis. Accomplishing the mission at lowest cost under nominal assumptions will be less important than having high confidence in mission success under a wide range of assumptions.

With this preface, joint field experiments—the usual focus of attention—should obviously be major features of warfare research, but *the big field tests should not be the tails that wag the dog,* as they are today. Many key experiments can be accomplished at small scale, and only some need even be joint.

This said, relatively large joint field experiments are often *crucial* for

- Demonstration, motivation, and breaking mental and organizational logjams
- Discovery (e.g., of new ways of fighting and new impediments to success)
- Integration testing
- Collection of information uniquely obtainable from such activities (e.g., information on real-world command-and-control effectiveness).

In contrast, large field experiments are *not* good for "covering the scenario space"—i.e., for understanding operational capabilities as a function of everything from context and strategy down to details such as warning time or the effectiveness of particular C^4ISR systems. Further, large field experiments by themselves seldom "prove" anything (e.g., the validity of a new operational concept and its implications for acquisition, doctrine, and organization) because of the limited circumstances examined.

If analysis is so important to transformation research, then, how should it be pursued?

Using Analysis to Guide Experimentation

The analytical approach that we suggest has a number of key features:

- A *decision perspective* supported by a decision-argument-hypothesis-analysis process, focusing research and experiments on issues central to potential decisions.
- *Hierarchical decomposition* of the operational challenges into building-block challenges that can be studied more or less independently.
- A *system perspective* highlighting the need for well-understood building blocks that can be combined with short notice in integrated operations under diverse circumstances.
- For each building-block operation, an *analytical architecture* supported by a family of models that can be used for
    - *Exploratory analysis* to understand issues associated with meeting the challenges in a vast scenario space (including detailed circumstances) and to identify issues and context for in-depth study.
    - In-depth *high-resolution analysis* to understand underlying phenomenology—even down to the level of sensor logic, weapon times of flight, and command and control

interoperability—and to use that understanding to help shape the higher-level, lower-resolution exploratory models.

- *Integrative analysis* at the operational and strategic levels.
- *Guidance for research and experimentation*: focusing experiments on issues that cannot be resolved with gaming and computer modeling (e.g., issues involving decisionmaking and integrative capability in dynamic operations).
- *Iteration* to improve knowledge until a self-consistent picture emerges that is strong enough to support decisions under uncertainty regarding investment, new "provisional units" that would be tested in warfighting commands, new doctrine, and changes in personnel policies.

Illustrating the Approach for the Operational Challenge of "an Early Halt"

We illustrate the approach by applying it to the operational challenge of achieving an early halt of an invading armored force while relying primarily (in this first example) on long-range joint interdiction by missiles, aircraft, and attack helicopters. We also discuss briefly the potential role of early offensive actions by small maneuver forces inserted behind enemy lines for actions against support structure and reserve maneuver units.

Although intended primarily to illustrate an approach, our accumulated analysis over the past two years has also generated many insights about the early-halt challenge. In particular, from work on desert and mixed-terrain cases, we conclude:

- An early halt (e.g., in Kuwait) is very difficult, but feasible in some circumstances.
- Capability assessments of such matters should recognize the upside of uncertainty, particularly the potentially poor performance and staying power of adversary maneuver forces. Otherwise, both feasibility of operations and the value of potential new capabilities will be severely underestimated. Further, doctrine and strategy will be unduly constrained and deterrence will be lessened.
- Slowing enemy advance rates is *critical*, suggesting the need to create bottlenecks and help defending allies conduct delay operations.
- Access problems are likely and could be quite serious, especially in crises involving mass-casualty weapons. The only reliable access may be prior presence such as we have today in the Persian Gulf.
- In preparing for diverse operational circumstances, there are high potential payoffs in (1) having forces in place that "lean forward" aggressively in response to strategic warning; (2) quick suppression of enemy air defenses (SEAD); (3) C^4ISR and "shooters" able to operate before such suppression is complete (adversary tactics can prolong SEAD); (4) high D-Day C^2 and C^4ISR competence; (5) achieving high-end effectiveness for fires directed against moving armored columns; (6) a "leading-edge" attack strategy; (7) a flexibility of long-range fires that might include long-loiter weapon systems (e.g., combat air patrol [CAP] stations) and a mix of weapon systems for attacking both moving forces and less dispersed and imperfectly concealed stationary forces; and (8) C^4ISR and weapons allowing late-in-flight target updates, moderately large footprints, and at least some sensing through foliage.
- Small maneuver units supported by long-range fires behind the enemy's lines have substantial potential for harassment, disruption, choke-point creation, and even direct attrition.

- The likely effectiveness of both long-range fires and small maneuver units is exceedingly situation-dependent. Having mixes of these capabilities to draw upon would be valuable to a future commander. In many cases, the values would also be synergistic.

Although much can be concluded from model- and wargame-based analysis, empirical information is essential on many issues, as noted above. Our analysis suggests specific tasks for joint experiments.

Priorities for Joint Experiments

The term "joint experiments" is somewhat ambiguous. A single service may conduct experiments "in a joint context"—i.e., operating by itself but attempting to account for other services' likely roles. Two or more services may, on their own initiative, cooperate in an experiment of joint capabilities, but without a joint commander. Or a joint authority such as USACOM may conceive and direct an experiment with several services participating. All of these are joint experiments in a broad sense, but only the latter type is usually referred to as a bona fide joint experiment. This is unfortunate, since it creates an artificial them-versus-us (joint commands versus services) perspective that makes little sense. Further, from a system perspective, most joint experiments in the broad sense (any experiment involving significant interaction among two or more services) *should* be conducted at as small a scale as possible so as to be able to do maximum exploration while controlling variables that need to be controlled. Most such experiments need not be overseen by a joint authority—so long as the experiments satisfy the system needs of planners concerned with future joint operations. That is, while joint authorities should have more influence on the priorities established for single- and multi-service experiments, executing those experiments is another matter. On the other hand, some joint experiments need the *direction* of a joint authority, presumably CINC USACOM, by virtue of its new responsibilities. Also, some joint experiments are too important to be hobbled by the requirement to save money and avoid disruptions by piggybacking on exercises primarily intended for other purposes. That requirement is today a serious problem.

Our conclusion is that CINC USACOM should focus work primarily on experiments concentrating on command and control, and on tests of both functional/technical and operational integration. Some such experiments can be small in scale and can even occur in command-and-control battle laboratories, while others should be medium- or even large-scale field experiments. ACOM's "experiment campaigns" should also include extensive gaming and analysis as discussed earlier.

Our work suggests that, for the halt challenge, it would be quite useful to have USACOM's experiments examine the following:

- *The "gain-competence time."* How quickly could a Joint Task Force (JTF) achieve full competence and efficiency in commanding and controlling long-range fires (and possible use of small ground-maneuver units) in a many-shooter, many-target, fast-moving situation? How would this time depend on prior training, in-place infrastructure, and systems?
- *C^4ISR system requirements.* How many and what types of C^4ISR assets would be needed in such a many-on-many situation given the potential for sensor and operator saturation? Again, how would the results depend on training and infrastructure? On sensor-to-shooter relationships?
- *Attack strategy.* When could long-range fires be effectively focused on the leading edge of invading forces, which in many cases would greatly reduce the invasion's effective speed as well as vulnerability to air defenses, but at the price of deconfliction problems (e.g., problems associated with numerous aircraft and missiles being used against targets in the same area)?

- *Dealing with the "dash problem."* How could air forces and other long-range fires be given enough flexibility (e.g., with loitering in CAP stations, adaptive targeting, and weapon mixes) to deal with armies that maneuver in short bursts, spending most time in protective terrain or under camouflage?
- *D-Day effectiveness against moving targets.* Given the desire for an *early* halt, what C^4ISR systems, weapons, and operational concepts will make long-range fires effective in attacking moving armies before air defenses are reliably suppressed—given the potential for some air defenses to be hidden and inactive early in the conflict?
- *Small ground units.* How and when could small but lethal ground forces be employed early and deep to slow the enemy's advance and disrupt his cohesion?
- *Allies.* How and when could defending allies, or at least special units of such allies, be employed in slowing roles—given the support of U.S. C^4ISR, liaison teams, and long-range fires?

Our thinking has been organized around meeting an illustrative operational challenge (an early halt), not the development of broad "functional" capabilities such as communications interoperability or collaborative-planning systems (much less the "demonstration" of capabilities about which there is little doubt). Therefore, this analysis-driven set of priorities looks quite different from what is currently being planned and discussed for joint experiments. Functional capabilities and integrative demonstrations are important, but focusing on operational challenges has advantages for improving coherence, defining meaningful requirements, and *measuring output.*

Acknowledgments

Our research has benefited from discussions with many colleagues at RAND and in the larger analytical community, military officers involved in advanced-concepts work and experimentation, civilian officials in the Department of Defense, and members of the 1998 Defense Science Board Summer Study. In particular, Glenn Kent made many suggestions and Jeff Isaacson provided a thoughtful review.

Outline

- Review: a strategy for transformation
- Analytical methods to guide transformation
- Illustrative analysis
- Interim conclusions
  - Priorities for research and joint experiments
  - High-leverage capabilities needed from "the RMA"

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1. Review: A Strategy for Transformation

The Department of Defense has been motivated by both opportunities and necessity to transform the force over the years ahead. It plans do so by exploiting modern technology and new operational concepts, and by making related organizational changes. This will be an opportunity for U.S. forces to greatly increase their capabilities and, in some cases, reduce costs at the same time. At the same time, major changes will be *necessary*, to mitigate difficulties posed by even mid-level rogue states such as Iraq or North Korea. These difficulties include short-warning attacks and other so-called "asymmetric" strategies involving mass-casualty weapons, missiles, mines, high-lethality conventional weapons, exploitation of urban sprawl and innocent civilians, and coercion of regional states to reduce U.S. access.

We begin by reviewing and updating results from an earlier part of the "Transforming the Force" project, which developed and recommended a strategy to guide transformation. The rest of the briefing turns to analytic issues. We discuss the philosophy of our analytical approach and the general character of related methods. We then illustrate the ideas with analysis focused—at the suggestion of the sponsors—on the use of long-range precision fires for "the halt problem"—being able to halt an invading army quickly and without serious loss of territory or cities. From the illustrative analysis, we then draw interim conclusions about priorities for research generally and field experimentation more specifically, and about what concepts and technologies associated with the so-called "revolution in military affairs" (RMA) appear to have particular leverage for addressing the operational challenge of an early halt.

The project's suggestions on transformation strategy were published in an issue paper (Davis, Gompert, Hillestad, and Johnson, 1998) and have been briefed to a number of senior officials. The next two slides summarize highlights from that paper.

Background: Conclusions from Earlier Work

- **Transformation is complex technically and operationally —neither "administration" nor "coordination" is adequate**
- **Key concept for transformation strategy: organizing around "operational challenges"**
- **Need**
  - ***Responsible authority*** **to build architecture and define needs for joint building-block capabilities that will truly integrate**
- **Solution might involve a new Deputy CJCS and ASD(OSD), with ACOM and other CINCs playing change-agent roles**
- **Joint experiments should be *one* key element of broader warfare research on future operations**
- **Research must be guided by theory, hypotheses, and analysis concerned with robust capabilities in difficult circumstances**
- **PPBS system's "mind-set" must support transformation with similar emphasis**

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The most important high-level conclusions were those shown in this slide. Each item is nontrivial in the light of current practice.

In particular, developing the joint capabilities envisioned under the rubric of transformation[1] will be difficult technically and operationally: Not only will it involve the normal complexities of large-scale management, it will also require a degree of *integration* that cannot be achieved by mere coordination. "Network-centric" operations and "self synchronization"[2] cannot be accomplished by stapling service capabilities together. This complexity is not adequately appreciated.

In reviewing the situation in early 1999, we note that many related processes are now in place as the result of DoD's decisions in 1998. However, those processes are subverted by divided responsibilities, the multiple missions that burden some of the principals, and the inherent limitations of committee action. *Joint Vision 2010* (JV2010; Joint Staff, 1996) is a strong vision document, but efforts to implement it do not provide adequate guidance for the services, USACOM, and others. More top-down effort is needed.

Because accomplishing the needed transformation will be extremely difficult organizationally in the absence of a compelling threat or recent disaster,[3] we recommend organizing work around certain *operational challenges* that would focus attention and serve as forcing functions.

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[1] See Cohen (1997), Cohen (1998), and National Defense Panel (1997).
[2] See Cebrowski and Garstka (1998).
[3] The importance to military change of threats or disasters is a point of contention in the literature. See Posen (1984), Rosen (1991), Hundley (1999), and Isaacson, Layne, and Arquilla (1999) for good discussions. It is clear that military change *can* occur before disaster strikes, as evidenced by U.S.

To guide transformation, we recommend that the DoD assign responsibility to high military and civilian officials (e.g., an Assistant Secretary and a new deputy Chairman) who would focus almost exclusively on these matters and perhaps have long tenures.[4] We do not envision a General Staff or a large Joint Staff bureaucracy but, rather, a small, elite DoD group that would draw heavily upon the Commander in Chief of the U.S. Atlantic Command (CINC USACOM) particularly, other CINCs, federally funded research and development centers (FFRDCs), national laboratories, and industry. The services would continue to be the dominant source of innovation and effort, but joint-level work (i.e., with other services, rather than unilaterally) would be strengthened and CINCs would become change agents.[5]

Joint experiments, for which CINC USACOM will be lead,[6] will be a critical element of transformation, but they should be only one element of much broader warfare research on future operations. Until recently, at least, this breadth requirement has been poorly understood.[7] The research should focus on achieving robust and adaptive capabilities in difficult circumstances (i.e., on understanding and reducing risk and uncertainty), not merely on achieving adequate capabilities for nominal cases.

For innovations to be reflected in programs, the mind-set of the Planning, Programming, and Budgeting System (PPBS) should change to support the needed transformation. As an example, the traditional tokens of discussion (divisions, wings, and carrier battle groups) do not even address such crucial features of future capability as the information network and advanced weapons. Nor do they give prominence to operational uncertainties, risk, and adaptiveness.

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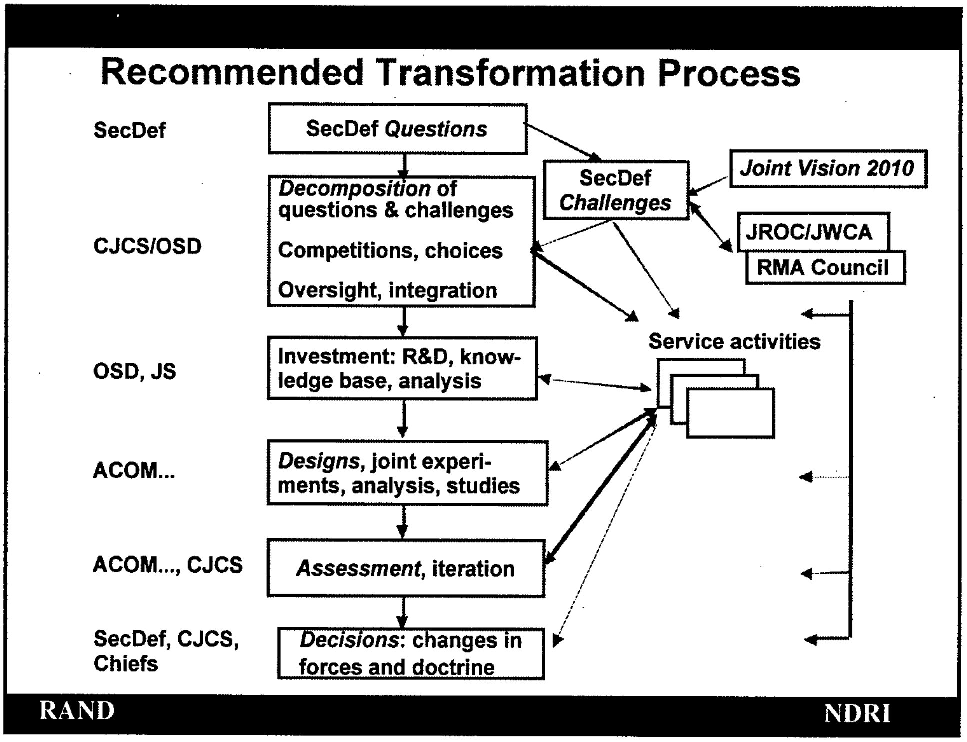
development of carrier aviation and amphibious operations in the years between World Wars I and II. Nonetheless, it does not come easily. Military professionalism can play a key role.

[4] Other solutions are possible. One would be to have either the Joint Staff's J-8 or the J-7 (but not both) play the role we suggest here for a new deputy chairman. The key is that clearly defined leaders are needed in both the Office of the Secretary of Defense (OSD) and the Joint Staff, and those individuals should not have responsibilities so numerous that they detract from their focus on transformation. Another possibility is that the current DoD approach will work. However, that approach involves divided responsibilities within the Joint Staff, an emphasis on weakly defined committee action, and individuals (the Chairman, Vice Chairman, J-8, J-7, and Assistant Secretary for Strategy and Threat Reduction) with multiple other responsibilities. Yet another approach would be to give even more responsibility for top-level planning and integration to CINC USACOM.

[5] Conventional wisdom has usually been that CINCs cannot be change agents because they are occupied with here-and-now problems. Our perspective is different. First, we note that many of the most dramatic aspects of "the revolution" involve already-available information technology and that the limiting factor is having determined users. Second, we note that current CINCs must already worry about the kinds of difficulties that can be expected to be widespread ten years hence. Thus, for CENTCOM to worry about increasing the lethality of forces that can deploy within days, or for PACOM to worry about how to attack and destroy enemy artillery quickly, is arguably natural. Further, if the CINCs and subordinate commanders are *not* enlisted as change agents, a prudent gambler might bet against the desired transformation's occurring: We believe that *joint* change agents are critical.

[6] See USACOM (1998) for the charter and a plan.

[7] This point is increasingly recognized, as evidenced by emerging plans at ACOM to include brainstorming, wargaming, and modeling and simulation activities as events under the rubric of joint experimentation. Doing so is also consistent with the original guidance provided to ACOM by the Secretary of Defense (see, e.g., USACOM, 1998). Nevertheless, there is a stubborn tendency on the part of officers, officials, and Congressmen to build their thinking around the major field experiments. That tendency is exacerbated by the terminology of "joint experimentation" and the way funding is handled.



This slide describes the proposed strategy as a schematic *process,* which begins with the Secretary of Defense posing difficult questions about how future U.S. forces will be able to provide future Presidents, Secretaries, and CINCs with the operational capabilities needed to protect U.S. interests in plausible but difficult circumstances. These questions lead to *operational challenges* that will serve as forcing functions for change. The challenges selected should address specific problems that will become much more difficult as potential adversaries improve their tactics and weapons, especially with short warning or mass-destruction weapons. The challenges chosen should also be so difficult as to *require* exploiting advanced technology and developing new doctrinal approaches. Significantly, the Department has recently embraced this concept of challenges with initial emphasis on "the halt problem"—being able to stop an invading army quickly—and related interdiction capability.

These challenges could partly supplant use of Defense Planning Guidance (DPG) scenarios, which have traditionally been defined so as to be not too unusual or difficult, and which have therefore not served as forcing functions for *major* changes, nor for emphasizing planning for adaptiveness. The Department of Defense has recently come to use multiple scenarios for the mid and longer terms, and these are more stressing. They are less-effective forcing functions than the operational challenges, but they are useful for integrative total-force analysis.

Given appropriate operational challenges, a special deputy chairman or equivalent would decompose them into well-defined building-block joint operations and assign responsibilities. Although the Joint Staff has been vigorous in providing a joint vision (Joint Staff, 1996), an elaboration (Joint Warfighting Center, 1997), and a listing of "desired operational capabilities" (Joint Staff, 1998), these efforts have been short on specifics and military context. For example, the desire for information superiority has led to desired operational capabilities (DOCs) involving "battlespace awareness" and subordinate DOCs on awareness of weapons of mass destruction. These *functional* capabilities are, indeed, important building blocks, but they do not provide the coherence and specificity of requirements possible by focusing on building-block *operations* (e.g., early halt or, at a subordinate level, air-defense suppression). Structuring in parallel around

both operational challenges and cross-cutting functions is needed, but relatively more work on the former is needed currently to provide the necessary coherence.

Problem decomposition would be followed by an iterative process involving concepts, analyses, experiments, assessments, and decisions. The vast majority of innovation and work would be done by the services, but in an integrated joint context. This is a central issue. Some critics of current DoD practices suggest moving toward a single "purple" force or establishing a large multi-layered joint staff. Our strategy instead seeks to leverage existing strengths and encourage bottom-up competition and innovation. At the same time, it envisions firmer joint guidance on needs. Much of the iterative work would depend on model-supported analysis: It is neither feasible nor desirable to address all the crucial issues with large field experiments. Unfortunately, DoD's current and emerging analytical tools are not up to the job.[8] One purpose of our work is to define better what tools are needed.

[8] See National Research Council (1997), which concludes that the problem is not a lack of computer programs but, rather, of knowledge about what to put into such programs.

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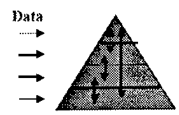
2. Analytical Methods to Guide Transformation

Let us now turn to our recent work, which describes analytical methods to inform, guide, and interpret research, particularly joint experiments. We start with a general analytical approach.

Key Elements

- *Decision perspective*
  - Concern for both breadth and depth
  - Understanding and reducing risk
  - Capabilities-based planning for broad scenario space
- *System approach* to military challenges
  - Top-down hierarchical architecture within network-centric construct
  - Bottom-up problem solving and competition
  - Model families
    - Multiresolution
    - Alternative perspectives and scopes
    - Cross-calibration
    - Simple and complex



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Our general approach has two key elements.

First, it takes a *decision perspective,* which focuses research, including experiments, on issues central to potential decisions, rather than searching for knowledge generally. Also, it recognizes that to serve decision needs, some matters must be understood in both breadth and depth, and the key issue of risk must be understood so that it can be reduced. As a whole, the approach is in the spirit of *capabilities-based planning* for a broad scenario space.[9]

The second principal element is a *system* perspective. Top-level joint-warfare capabilities depend on the net effect of many interactions among building-block operations, activities of the adversary and allies, environment, and so on. It is not enough to build longer-range weapons or to improve communication bandwidth: *overall* Joint Task Force (JTF)–level operations must also work. This comprehensiveness will be more difficult to achieve in the future because more of the critical operations, suboperations, and even tasks will require synchronization across service components. That is, jointness will extend deeper.

To understand the system features of the operational challenges, it is necessary to combine top-down and bottom-up methods. Even top-down methods must account for the network-centered aspects of future operations and facilitate bottom-up adaptiveness—especially since most innovation in our society tends to be bottom-up in origin. The function of the "top" *should be* to identify key challenges and needed building-block capabilities, to establish suitable environments (e.g., a marketplace and a powerful "information grid"),[10] and to ensure that both integration and at-the-time custom tailoring of operations will be feasible when necessary. This is quite different from specifying an integrated system from the outset.

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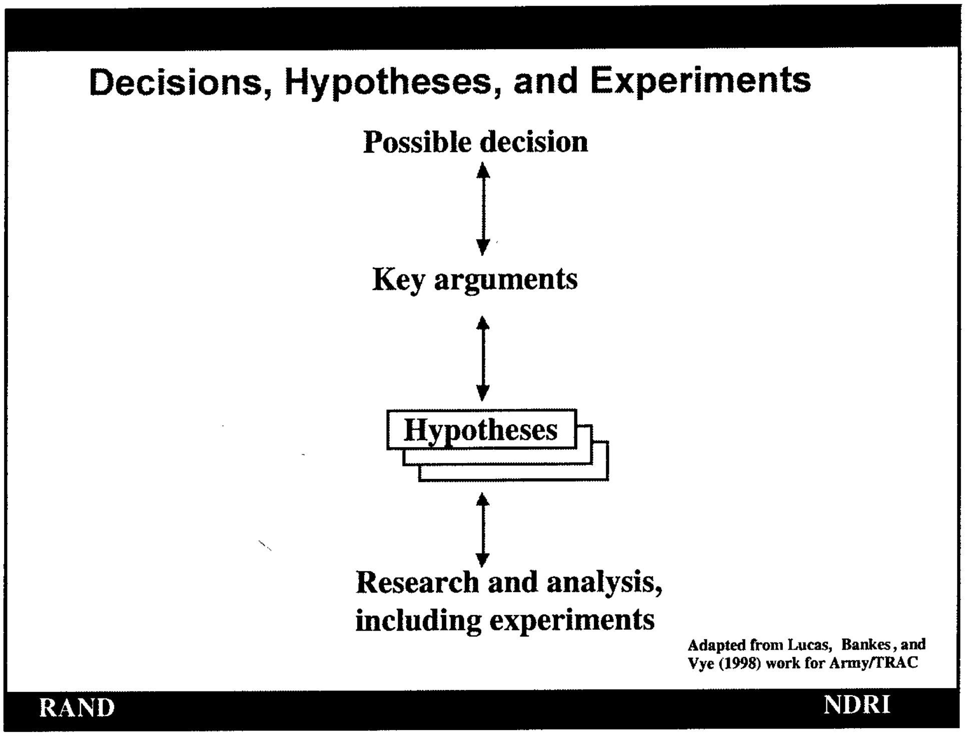
[9] For discussion of capabilities-based planning and why it is different, as well as the scenario-space concept, see the "Planning for Adaptiveness" chapter in Davis (1994) and Davis, Gompert, and Kugler (1996). This concept is quite different from that in which "capability" refers to "functional" matters such as communications or information. However important, such functions should no more drive DoD thinking and analysis than should corporate functions such as accounting or computer services.

[10] See Johnson and Libicki (1996), especially the chapter by Admiral William Owens, and Libicki (1999), which discusses the information grid.

An important feature in such an approach is having a multiresolution *family* of appropriate models and simulations, as well as related analytic methods, all of which, ideally, would be integrated so that knowledge at different levels and from different perspectives could readily be used to develop an overall best depiction of phenomena consistent across levels and perspectives.[11]

[11] See National Research Council (1997) and Davis and Bigelow (1998).

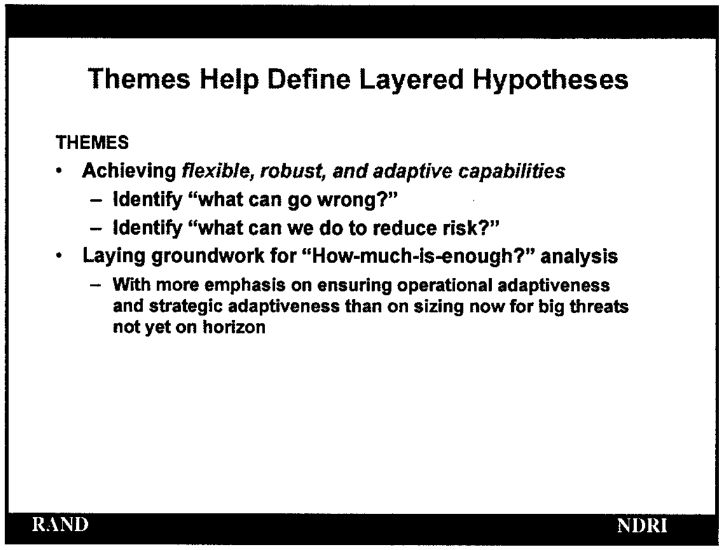


Let us now consider in more detail what we mean by a *decision perspective.*

This slide[12] suggests that, in considering how to go about research, including experimentation, it is not enough to pose hypotheses (the commonly stated requirement). Instead, we should imagine *decisions* that might come about as the result of the knowledge for which we are searching. *That is, the research needed is not merely to increase knowledge—as in curiosity-driven basic science—but to help inform options and choices.* In this context, we do not refer to specific "decision points" such as those in a given weapon system's acquisition process. Rather, we have in mind potential decisions not yet on any current decision schedule.

It is also useful to imagine—to simulate in our minds or written sketches—what arguments would be decisive in reaching the decisions at issue. That is, why might we come to believe certain actions were appropriate? Identifying these arguments would lead to layered hypotheses, which could then drive design and interpretation of experiments.

[12] This structure is adapted from prior work for the Army (Lucas, Bankes, and Vye, 1998).



We suggest two themes in defining layered hypotheses. First, we should seek *flexible, robust, and adaptive capabilities* by worrying about what can go wrong—and about what can be done to reduce risk.[13] This focus is quite different from expressing hypotheses for, say, a technology demonstration under controlled circumstances.

Another theme should be laying groundwork for understanding "how much is enough?"—though not in the usual sense of *enough.* We are concerned that those hoping that advanced systems and concepts will revolutionize warfare often overestimate effectiveness and underestimate quantitative needs—because they tend to be optimists and to have incentives for keeping estimated price tags low.[14] One mission for analysis and experiments is to clarify when redundant capabilities are needed to hedge against difficult operational circumstances resulting from, e.g., clever tactics, countermeasures, losses of important systems (e.g., Joint Surveillance and Target Attack Radar System [JSTARS] aircraft), and the fog of war. Such redundancy improves *operational adaptiveness.* Another mission is to identify potential capabilities that, if they prove feasible and affordable, would have high value against plausible future threats. By developing such capabilities (but not necessarily fielding them in quantity), the United States would be much improving *strategic adaptiveness.*

[13] We use definitions from work done for the Joint Staff by Davis and Finch (1993). "Flexible capabilities" can be used in diverse missions and theaters; "adaptive capabilities" can be reconfigured into new units or employed in new operations; "robust capabilities" can withstand difficulties such as surprise or initial losses. Depending on context, "capabilities" may refer to units, systems, or building-block operations.

[14] This point has been strenuously made by Richard Kugler of the National Defense University.

Analytic Techniques

- Decomposition trees
- Model families
- Exploratory analysis
- Focused hi-res analysis and experiments
- Integrative analysis and joint experiments

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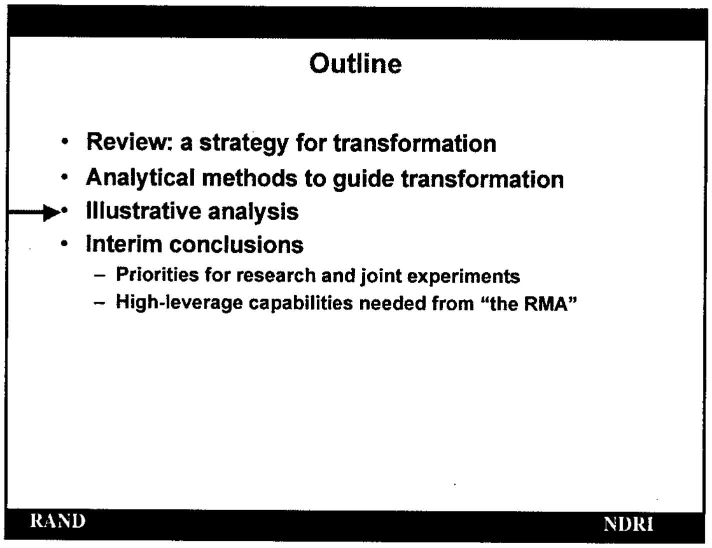
Given a decision perspective and a systems point of view, the analytical techniques mentioned in the slide become central. Decomposition trees help move from a high-level operational challenge to component joint operations and suboperations that can be studied more or less independently. Model families are important, because we need to use all the information available at any level of resolution, or from any of many perspectives, to develop a rich understanding of the warfare phenomena. Given such families, we can do exploratory analysis for breadth, more-focused, high-resolution analysis for depth, and integrative work in which we study how various building-block capabilities can be harnessed as part of a complex JTF operation.

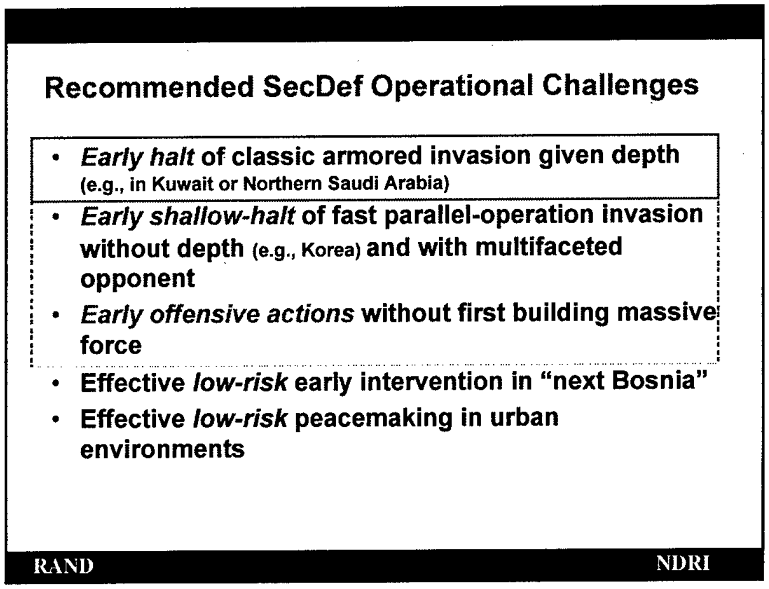
Our approach may appear overly complex and analytical at a time when discovery-oriented field experimentation is obviously needed. However, most of what we are advocating is standard procedure in successful large-scale activities that involve technical and operational complexity with associated requirements for integration and synchronicity.[15] Experimentation is critical, but so also is analysis—especially because experimentation will necessarily be quite limited.

[15] See Davis, Gompert, Hillestad, and Johnson (1998) for examples and further discussion. It is notable that the image of future warfare painted in *Joint Vision 2010* is much more complex technically and operationally than traditional military operations, especially those resulting in so-called attrition warfare.



3. Illustrative Analysis

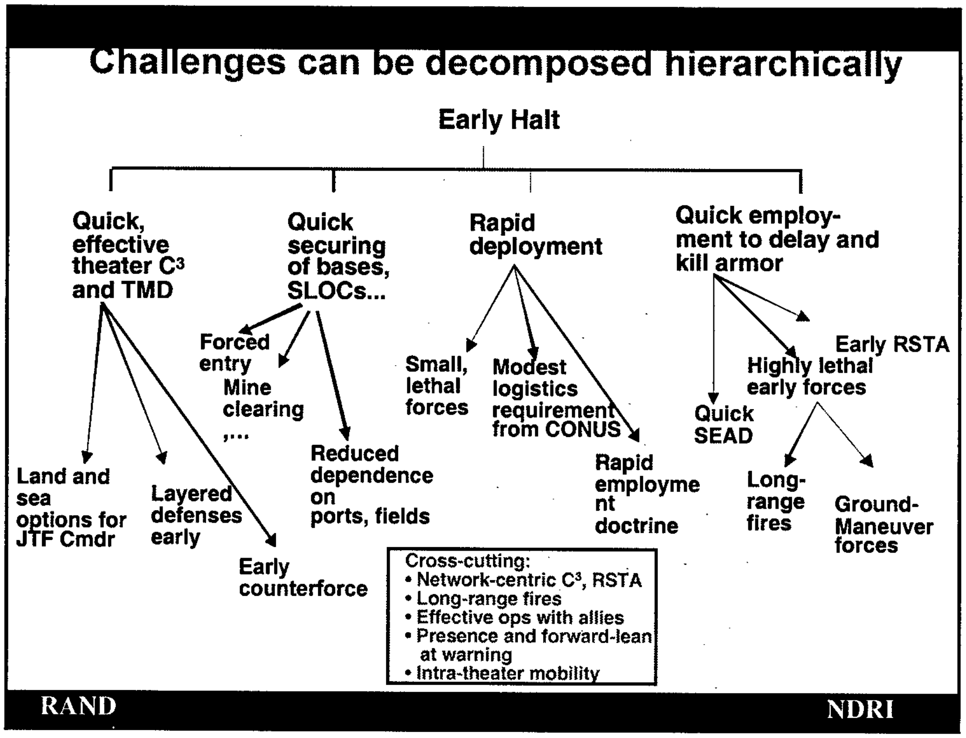
Let us now sketch an example from beginning to end. We start by suggesting challenges, narrow our focus, use the decision-argument-hypothesis framework and system perspective, and then illustrate how analysis can be brought to bear. In the process, we reach a number of conclusions about priorities for joint experiments. We also identify some futuristic capabilities that would be especially valuable. Despite the sketchiness of the presentation and the work's in-progress character, we hope to demonstrate the potential value of analysis in guiding transformation research.



This slide shows the operational challenges we have suggested in the current project. We concentrate here on the first, which plays to long-range precision fires and establishes a stressful joint mission that cannot be accomplished by waiting a week or two after deployment until an advancing enemy army eventually gets to where U.S. ground forces are. The second challenge, in contrast, recognizes that some early halts will *not* readily be accomplished by long-range precision fires and will require a very different mix of forces, including ground forces. One might think today of Korea, but there are many possible future wars in which the preferred first move of the enemy would be sudden and decisive, and would not involve long desert marches. This problem lends itself to solutions with highly capable and rapidly deployable Army and Marine forces, and packages to assist allied forces in place (as well as air forces, long-range naval gunfire, and missiles).

The third challenge puts squarely on the table the requirement to find out whether "dominant maneuver" and "information dominance" are meaningful and feasible. If so, then it may be feasible and desirable to begin attacking into an invading enemy's rear area from the outset of hostilities, attempting to fragment and collapse that enemy. As a minimum, such operations might assist in bringing about an early halt. Even better, they might change the very phasing of operations so that the enemy is not only halted but also collapsed in a first phase. Large-scale counteroffensive operations would also be needed, but they might not require as extensive a buildup and might not have to deal with a coherent dug-in adversary.

Let us now illustrate the method of decomposing these challenges.

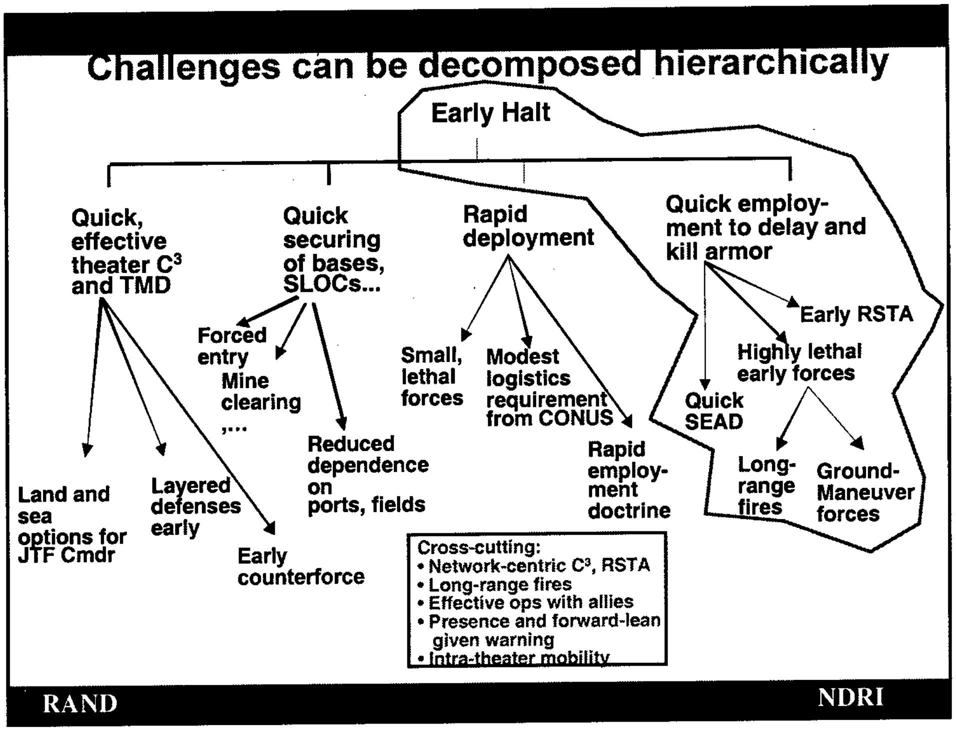


Each of the challenge problems is the outer shell of a multilayered structure. To say on a viewgraph that the United States should be able to bring about an early halt is straightforward, but accomplishing the challenge requires many building-block capabilities. For example, on the left of the figure, we see the requirement to establish quick and effective command-control and theater air and missile defense. Moving to the right, we see the need to secure bases and, e.g., the potential need for forced entry. In many cases, success of the whole requires success of each part. That is, we have a complex *system problem.*

Such decompositions can be used managerially to ask questions such as, "Who is going to guarantee that each of the requisite building-block capabilities will be available when needed, and will be amenable to efficient JTF operations?" and "How should responsibilities be assigned?"

As indicated in the box at the bottom of the slide, certain crucial features of capability are cross-cutting; therefore, they do not appear in any single branch of the decomposition tree. In particular, *all* of the subordinate operations are likely to depend on network-centric command and control,[16] long-range fires, ability to work with allies, forward presence, forward leaning during crisis (i.e., taking actions to prepare for war), and mobility. Such cross-cutting *functions* tend to be the focus of much Joint Staff work on desired operational capabilities (Joint Staff, 1998). The Joint Staff's use of the word *operational* seems to us unfortunate, because it often refers to what we call *functional* capabilities.

[16] See Cebrowski and Garstka (1998) for a visionary description of network-centric operations.



In the remainder of this briefing, we narrow down to one portion of the early-halt problem, indicated here within the loop. This portion involves a combination of long-range fires and, to some extent, early-available ground-maneuver forces that are used both to interdict and halt the enemy.

Potential Decision Motivating Research

- **Decision: create mid-term high-tech front-end force for very-rapid-deployment JTFs**

  Pursued also in 1998 DSB
- **Arguments:**
  - Current "rapid-deployment-force" is slow, vulnerable, scenario sensitive, and inefficient
  - New force would enhance deterrence and, in war, would *likely* prove extremely valuable—halting or greatly slowing invasion early and avoiding costly and dangerous counteroffensives
  - Experience with such a force "in the field" would change attitudes and motivate further transformation

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→• Decision
→• Arguments
• Layered hypotheses
• Analytical and empirical research

Given the halt challenge and its decomposition, let us now consider how we might use analysis to think about research generally and experimentation specifically. We wish to take the decision perspective mentioned earlier.

One quite plausible decision to motivate research would be to create a mid-term "high-tech" front-end force to help a JTF commander in the very early phases of operations—the first *hours and days* of operations. The need for such a front-end force has been a theme in this and earlier projects for some years.[17] Whether any such decision will be made remains to be seen, but it is the *kind* of decision that may be of interest as the United States investigates alternative operational concepts. The 1998 Defense Science Board converged on this decision in its Summer Study work.

If such a decision were to be made, what would the argumentation for it be? As the slide indicates, the arguments would address both the inadequacy of current capabilities and the potential value of the postulated force. Moreover, they would emphasize that the postulated front-end capabilities would be useful not only for very-rapid-deployment cases but for many other cases as well. Finally, it would be argued that experience with a first version of such forces would have broad value in motivating further transformational activities. That is, the experimental force would be valuable, as part of a *process,* even if imperfect as a model of what forces 15 years from now should be.[18]

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[17] See, e.g., Davis, Schwabe, Narduli, and Nordin (unpublished); Davis, Gompert, and Kugler (1996); and Davis, Hillestad, and Crawford (1997).

[18] This would be akin to the "provisional capability" suggested in Hundley (1999) based on historical analysis of military and commercial revolutions.

Some Underlying Hypotheses

Higher Level

- We know how to build such a force "now"
- Early halt is feasible in many cases, even against smart adversary
- Benefits would be high and down-side risk would be tolerable
- Force fielded soon would be good base for further evolution and transformation

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- Decision
- Arguments
- → Layered hypotheses
- Analytical and empirical research

To sustain the arguments of the last slide, it would be necessary to believe a number of items that can only be considered hypotheses at the moment. This slide shows high-level hypotheses, none of which were self-evidently true as of early 1999.[19]

In what follows, we focus on the feasibility of an early halt. The hypothesis stated is that an early halt is feasible *in many cases*, but is not a panacea. However, the hypothesis explicitly allows for a "smart adversary," by which we particularly have in mind an adversary that, e.g., gives short warning and uses chemical or other mass-casualty weapons.

[19] We use *hypothesis* in a fairly general way that includes suppositions appropriate to discovery and exploration, not just the kind of narrow postulations that are grist for statistical interpretation of hard experiments. For discussion of how different uses of terminology on words such as *hypothesis* can confuse discussion, see Worley (1999) and Hayes (1999).

Hypotheses with Greater Detail

- Such a JTF could halt invader within a few days or greatly reduce enemy forces for close combat
  - Improving odds of good outcomes with only modest risk
- Key success factors: suitable PGMs for air forces and missiles; superb information
  - Long-range fires could stop an invading army
  - Ground-force maneuver units could be employed early against attacker's rear area

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Hypotheses can be layered, from broad to specific. This slide adds more detail, referring to halting an invader within "a few days." It further asserts that the key to success would be long-range fires with precision-guided munitions and perhaps ground-maneuver units inserted behind the attacker's line.

In passing, let us note that we are *not* among those enthusiasts who have much hope that long-range fires alone will often be adequate: "Boots on the ground" will usually be critical—sometimes even in early operations. However, it is plausible that such fires can in *some* cases make classic large-scale armored invasions obsolete, undercutting the preferred strategy, force structure, and doctrine of many rogues with Soviet-style equipment and doctrine.[20] It is this hypothesis we are exploring here. Some hypotheses, of course, prove to be wrong.

[20] This point was stressed by Major General Jasper Welch (USAF, retired) in a DSB study (DSB, 1996b). For a list of plausible countermeasures to long-range fires, see the same study or Appendix D of Davis, Schwabe, Narduli and Nordin (unpublished).

Hypotheses (cont'd): Some likely problems

- **Potential Achilles' heels:**
  - Mining, threat or reality of WMD, surprise attack
  - Problems with D-Day C^3 and RSTA
- **Success could depend on leveraging allied capabilities**
  - Is feasible with prior training and pre C-Day actions
- **SEAD can (or cannot) be ensured within a few days**

  •
  •
  •
- **Classic air-tasking-order (ATO) methods undercut network-centric forces.**
  - Need enroute assignment and updating

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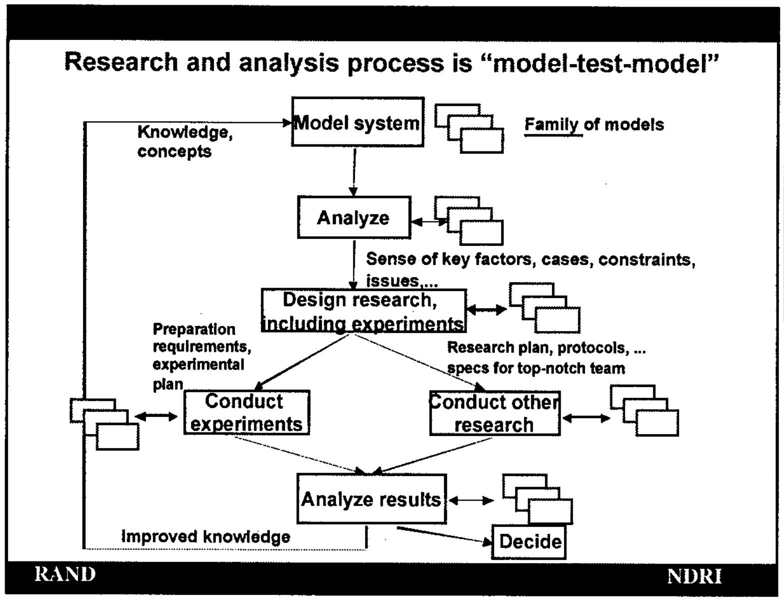
Going even more deeply into detail, the hypotheses would specify smart enemy actions (sometimes called "asymmetric strategies"). Many of these would exploit Achilles' heels such as the U.S. need for time to deploy forces, secure ports and airfields to accept them, and immediate C^3 and reconnaissance, surveillance, and target acquisition (RSTA) to guide operations. The hypotheses would also identify smart ways for the United States to operate (e.g., with allies). Further, the hypotheses would include reference to subordinate operations such as suppression of enemy air defenses (SEAD). A complete list would be much longer, of course.

At an even deeper level of detail, an illustrative hypothesis is that classic air-tasking-order (ATO) methods will prove inappropriate, undercutting the ability to use interdiction well. This is a good example of an uncertain hypothesis: To some observers, the ATO process is symbolic of obsolete doctrine; to others, it is the core of planning—something that can be streamlined, but not eliminated. For example, an ATO might allow for a great many sorties to be dispatched, with targets to be specified en route.[21]

[21] The cycle time for ATO preparation has traditionally been a day or two, which is quite long for dealing with many targets such as moving armies.



- Decision
- Arguments
- Layered hypotheses
- → Analytical and empirical research

Given a possible decision, likely arguments for such a decision, and the hypotheses needed to sustain the arguments, we now have a rich basis for conceiving and defining research, including experiments. This slide reminds us that the overall process should be one of *model-test-model*, by which we mean that our eventual understanding of the phenomena will be embodied in models and simulations, and that we can do only limited experimentation to help inform and calibrate those models: That is, the experiments are crucial, but are ultimately insufficient. Judgments and decisions will depend on synthetic knowledge, whether in the form of computer models or less-rigorous "mental models." The triplets of rectangles in the figure represent families of models that would be employed at each stage of the iterative process.

Although this model-test-model (M-T-M) paradigm is well established, we offer one important caveat. If one understood "model" to mean a closed computer simulation, then most military officers attempting to think creatively about future tactics and doctrine would find the M-T-M paradigm utterly noncredible, possibly observing, for example, that the computer simulations they are aware of impede rather than assist exploring the potential of innovative concepts—in part because the assumptions often embedded in simulations are tied to current tactics and doctrine, and in part because they are so abstract. Such officers might reasonably observe that, while analysts might consider field experiments to be expensive and unscientific, the great innovations of carrier aviation and amphibious operations owed much more to brainstorming followed by field work than to mathematics and computers (which did not even exist).

Our rebuttal here has two parts. First, we believe it essential to conceive of such activities as brainstorming, small-scale human war gaming, and war gaming with human command-and-control decisions as examples of modeling—at least if there are structured efforts to draw conclusions (e.g., identify key factors and note general tendencies). Without this extension of the concept of "model," the M-T-M paradigm does indeed fail. Our second point is that the operations envisioned in *Joint Vision 2010* involve much more complex and integrated military

operations than anything in past military history. To deal with these operations adequately will, we believe, require the M-T-M approach.

What might a family of models look like?

- Factor identification and case structuring from brainstorming and human gaming
- Closed-form analytic MRM spreadsheet halt model
- Somewhat more general MRM spreadsheet halt simulation
- Moderately complex MRM "system halt model" in visual-modeling framework (Analytica)
- Campaign model for integration (JICM)
- Simple, focused high-resolution model to study measure-countermeasure issues in "dash"; others
- High-resolution battle model (Janus level)
- Community DIS confederation (TACWAR, EADSIM, ...)

MRM: multi-resolution models

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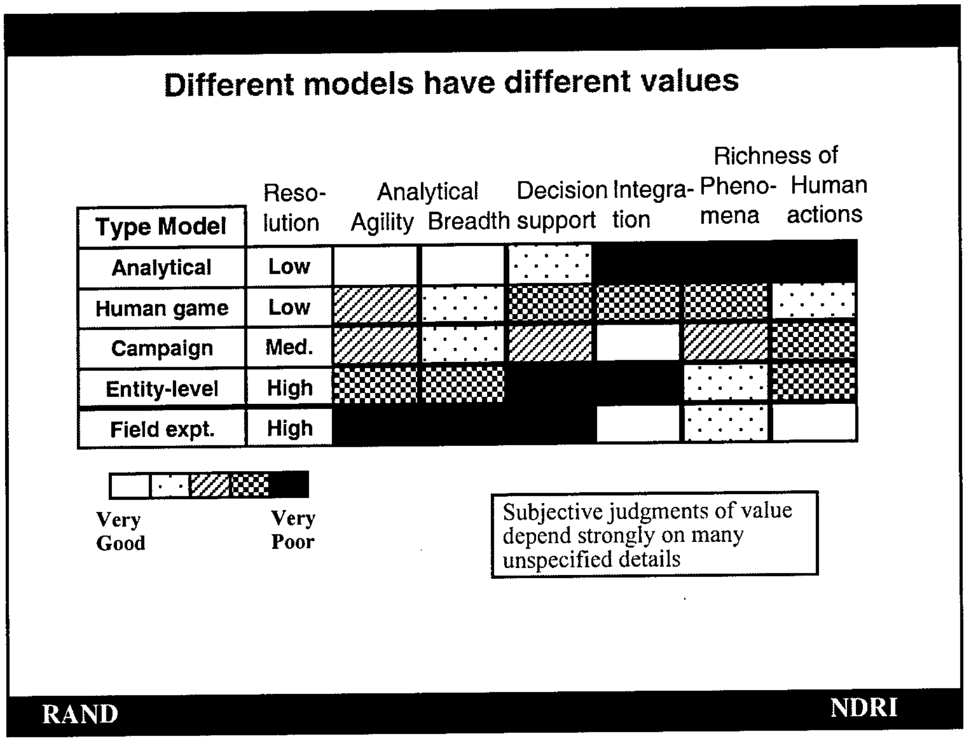
We have mentioned the importance of model *families*. But what might such a multiresolution family look like? This slide suggests that the desired stable of models would be rather large. It would include everything from structured lists of factors and cases inferred from human war games, to simple, closed-form back-of-the-envelope formulas, to large exercises using distributed interactive simulation (DIS) and a mix of live and simulated systems. Agent-based models (i.e., models with submodels making human-like adaptive decisions, sometimes with a degree of randomness) can subsequently represent concepts from human games.

For this prototype activity, we built some of the simple models; we drew upon other RAND research for integrative work with JICM and high-resolution simulation at the Janus level. Had there been time and opportunity, we would have gone farther to consider ways to use community federates such as the EADSIM and AWSIM models.

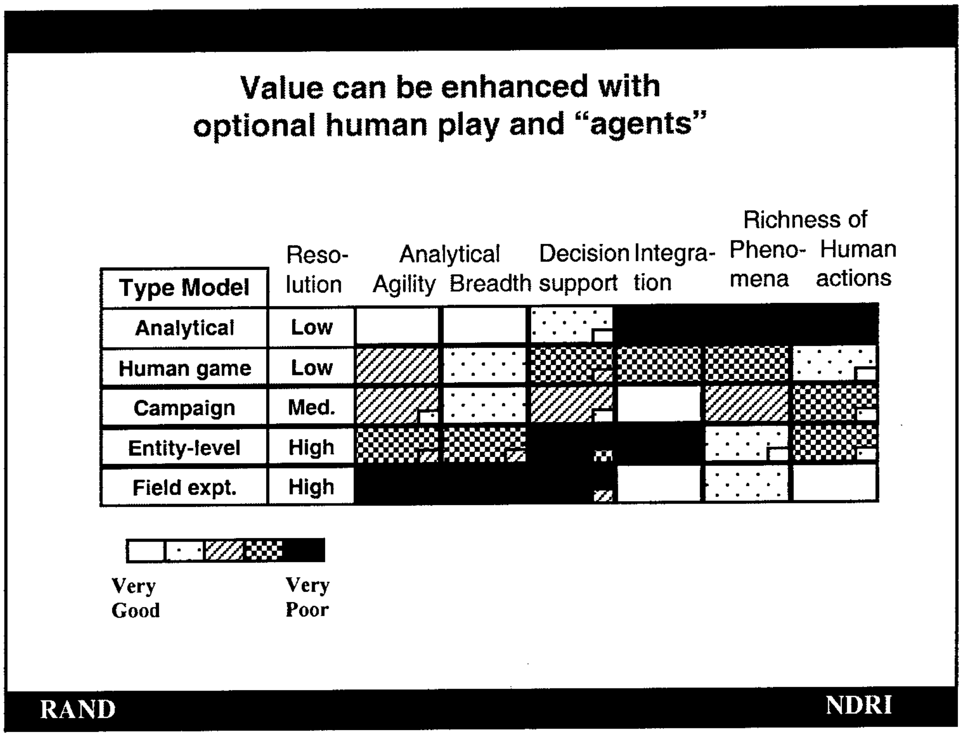


To elaborate on the use of model families, consider that different members of a family are good for different purposes. This slide[22] characterizes some models in terms such as resolution, and ability to address diversity of scenario, subtle phenomenology, and human behavior. The principal point is that simple, aggregated, low-resolution models (top row) are uniquely valuable for exploratory analysis across a broad range of cases and, thus, for considering adaptiveness, flexibility, and robustness (see green or—in a gray-scale printing—white cells at top left of scorecard). These types of models can sometimes be implemented in closed form or, more often, in spreadsheets such as Excel™ or visual-modeling systems such as Analytica™ or iThink™. However, their value depends on whether they adequately reflect underlying phenomena to which they give no visibility at all (see red or dark scores, at top right).

As we increase the scope and, to some extent, the resolution of our analysis, we need more-complex models such as JICM at the operational or theater level. Such models are typically less agile and less easy to work with creatively (although JICM is superior in this regard to the older models), but they are more integrative and have more flexibility in describing phenomenology involving units and their interactions with terrain, maneuver, mobility, and so on. To understand a phenomenon at a deeper level involving individual platforms or even weapon systems, we need higher-resolution models and, when the phenomenon depends strongly on human decisions and

[22] This slide is similar in spirit to one presented in Lucas, Bankes, and Vye (1998).

behaviors, we need gaming and experiments of the sort one thinks of in connection with distributed simulation (see green or white cells at bottom right).



This slide, a simple variation of the previous one, shows with small rectangular insets the potential benefit of adding agents to the models. Although the term "agent" is usually associated with computer science—even state-of-the-art work in complex adaptive systems—we can think of agents in this context simply as decision models that represent many human-like considerations. Agent-based models can represent either decision processes driven from above in some detail or decision processes driven from below, with the agents (e.g., lower-level commanders or even individual combatants) operating with a strong sense of mission and a fairly small set of rules.

Such agent models *can be* vastly superior for analysis to scripted models, which lack adaptive decisionmaking, and especially well suited to studies of distributed, adaptive command and control, including network-centric versions.[23] At present, however, there are few such models. Further, some of those that exist are brittle, because they depend on rules sensitively dependent on current doctrine.

[23] See National Research Council (1997) for relevant citations, including the recent tactical-level work, for the Marines, of Andrew Ilachinski at the Center for Naval Analyses and earlier operational-level and political-level work by the principal author. Other examples include the semi-automated forces (SAFOR) used in some distributed simulation.

What Follows

For illustrative halt problem,

- Exploratory analysis with aggregate models
  - Very low resolution
  - "Moderate" resolution
- Selected "dips" into higher resolution
- Insights, suggestions

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In what follows, we examine the halt problem—first with exploratory analysis and then with selected dips into higher resolution. We then summarize insights from a substantial body of work.

Two tracks for exploratory analysis

Characteristic	Parametric exploration	Probabilistic exploration
Defers many assumptions until after survey	Yes	Optional
Deemphasizes baseline-case thinking	Yes	Optional
Considers outcomes in "cross-product space" of major variables	Yes	Yes
Outcome space shows cause-effect results for assumption combinations	Yes	No
Displays show cause-effect	Yes	No
Displays show "net assessment" of uncertainty	No	Yes
Can be done with desktop tools (given simple model)	Yes	Yes

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By "exploratory analysis," we mean an analysis examining a wide range of input assumptions while looking for broad insights, rather than, say, optimizing for a particular set of assumptions. This is more than sensitivity analysis, because—in practice—nearly all sensitivity analysis in problems with more than a few variables assumes a single baseline treated as being close to reality. The sensitivities are then excursions pivoting around that single point or scenario, one by one. In contrast, exploratory analysis is a *comprehensive* sensitivity analysis that examines the effects of *combinations* of variable values.

We have developed two means for doing this exploratory analysis. The first is what we call *parametric exploratory analysis,* which considers a discrete range of values for each variable and computes model results for all the combinations. Combinations may amount to thousands or even millions. The results can be reviewed visually to see what combinations of assumptions lead to very good, very bad, or gray-area outcomes.[24]

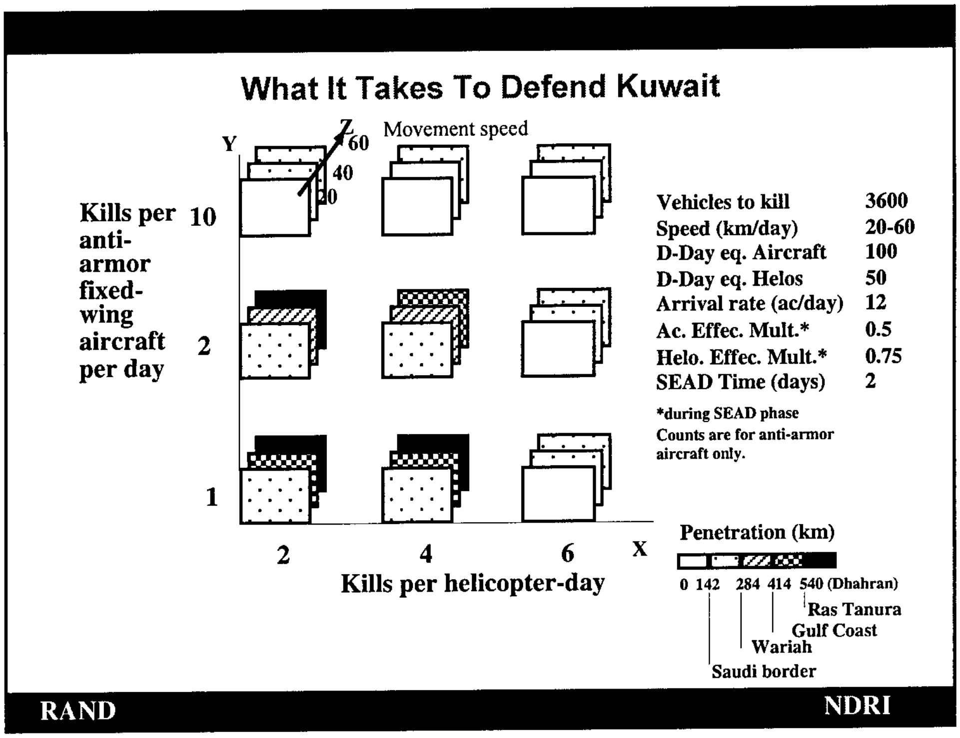
The other approach is what we call *probabilistic exploration*, in which the uncertainty of each variable is characterized with a probability distribution. For example, we might assume that the attacker's rate of advance is equally likely to be anywhere between 20 and 80 km/day. Then we can use Monte Carlo methods to generate the uncertainty of outcome resulting from the

[24] The concept of exploratory analysis in force planning goes back at least as far as Davis and Winnefeld (1983), but the technology needed is much more recent. See in particular Bankes (1993) and other citations in NRC (1997). The tools for desktop probabilistic exploration are even more recent (e.g., RAND's Data View, developed by Steve Bankes and James Gillogly, and the commercial products Crystal Ball® and Analytica®).

uncertainties in many assumptions. This process provides more of a simple net assessment, but at the expense of obscuring precisely what combinations result in what outcome.

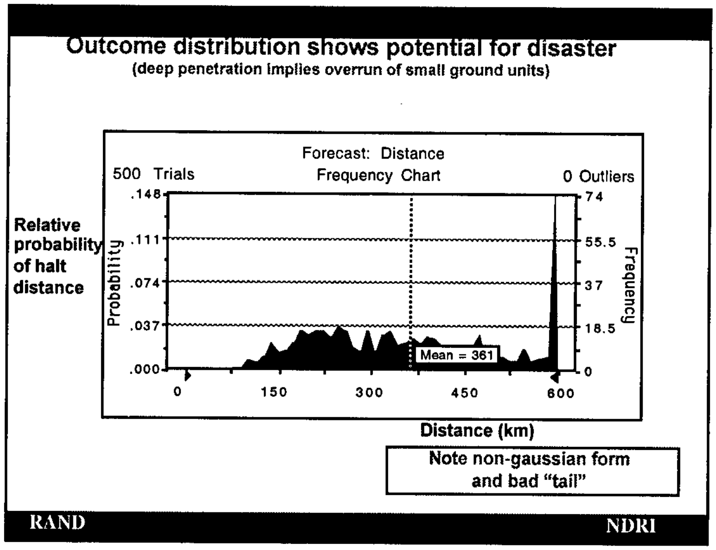
We have been experimenting with both methods, because they are complementary. We also use many hybrid versions that treat some of the variables parametrically and others probabilistically. Each method has its own technical difficulties and a great many subtleties, which take a good deal of time to understand. We have also been experimenting with a variety of software tools and displays. In this briefing, we touch on five types of display:

- A snapshot display from an interactive RAND system (DataView) for viewing results of parametric exploration as a scorecard
- A curve of outcome probability illustrating the more reductionist results of probabilistic exploration
- A standard analytical graph comparing results, in a particular scenario, for two specific force-employment strategies
- Two fuzzy-logic outcome tables that provide a language-oriented way of viewing results of exploration
- A three-dimensional response surface showing parametric results.



This slide shows a DataView display from a low-resolution parametric exploration by Davis and Carillo (1997). We have used such displays also in many theater-level analyses including the effects of ground forces, prepositioning, weapons-of-mass-destruction (WMD) attacks, mines, and other factors. Green (or white in a gray-scale printing) indicates that the attack was stopped quickly (Kuwait or Saudi Arabia). Red (or black in gray-scale) means that the attacker penetrated to long distances (e.g., to the outskirts of Dhahran). The x, y, and z axes show three key variables as shown.

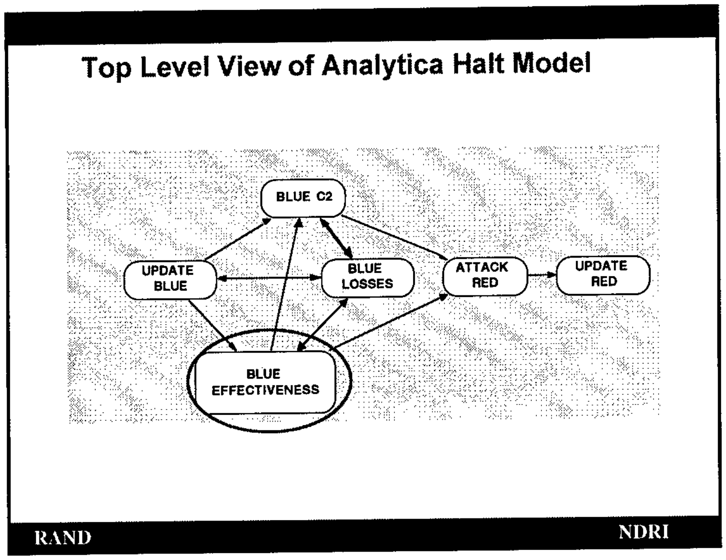
Online, we can—with simple mouse operations—change which variables appear on the x, y, and z axes. Also, we can change interactively the value of variables shown in the right column. Thus, we can "fly through the outcome space" and learn a great deal within tens of minutes. If the model has sufficiently few variables (5–7), the results can be condensed to a half-dozen pages, each with four figures akin to the slide above. Reading the results requires some experience, but after perhaps 10 minutes invested, one can quickly see the circumstances for success and failure. In particular, the attacker's speed is a key variable, as are SEAD time and the number of shooters available on D-Day (and, less dramatically within the range of values considered, their lethalities). Deployment rates subsequent to D-Day are less important, because achieving an *early* halt depends primarily on forces being in place when the shooting starts.



This slide, taken from Davis, Gompert, Hillestad, and Johnson (1998), shows illustrative results of a probabilistic exploration using Monte Carlo techniques. It shows the relative probability of various halt distances when large uncertainties in the duration of SEAD, attacker speed, the number of vehicles that must be damaged to bring about a halt, the effectiveness of shooters, and their deployment rates have been taken into account. It holds constant some other variables. In context, the purpose of this particular figure was to show that even though a calculation with nominal assumptions might predict a halt within 360 km, suggesting that ground forces might be inserted up to that point, the risk of such forces being overrun as a result of uncertainties in the assumptions is quite sizable.

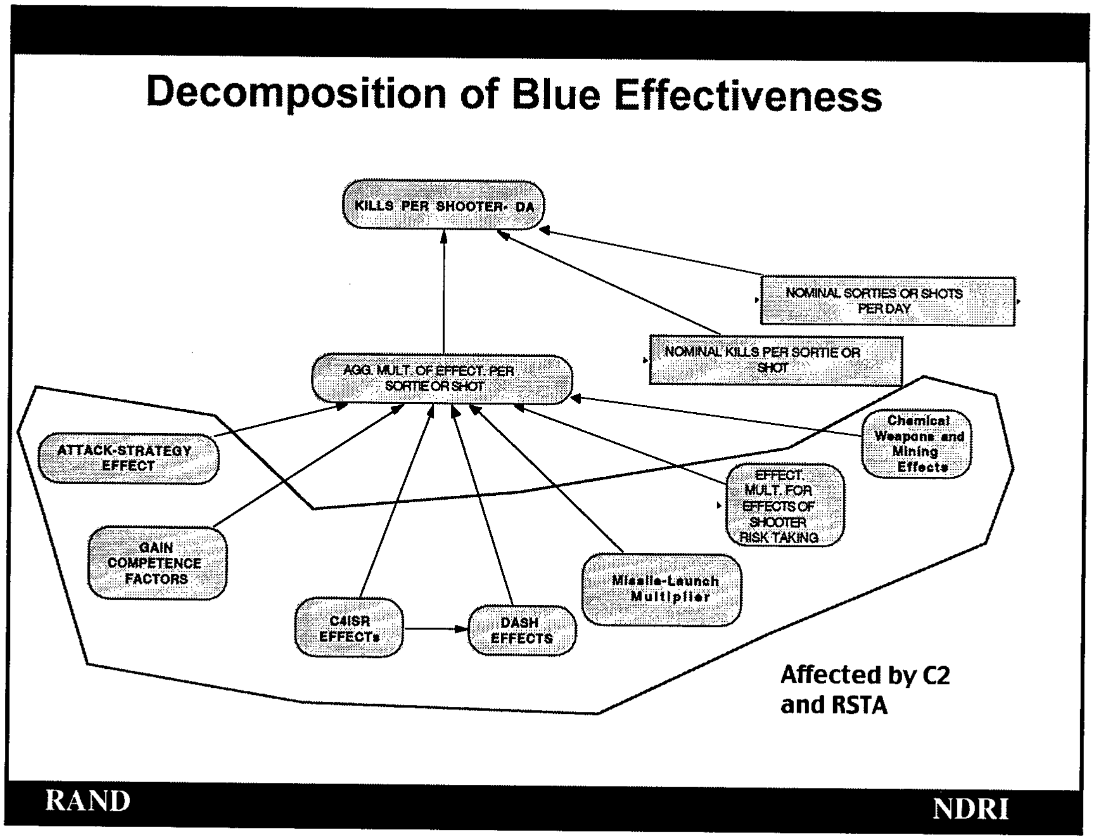
Here "probability" should be interpreted as a useful, albeit imperfect, measure of outcome likelihood, given input uncertainties about many factors. Of course, the calculations can be redone using different and specific assumptions about future capabilities.

We next illustrate exploratory analysis at a somewhat higher ("moderate") level of aggregation.



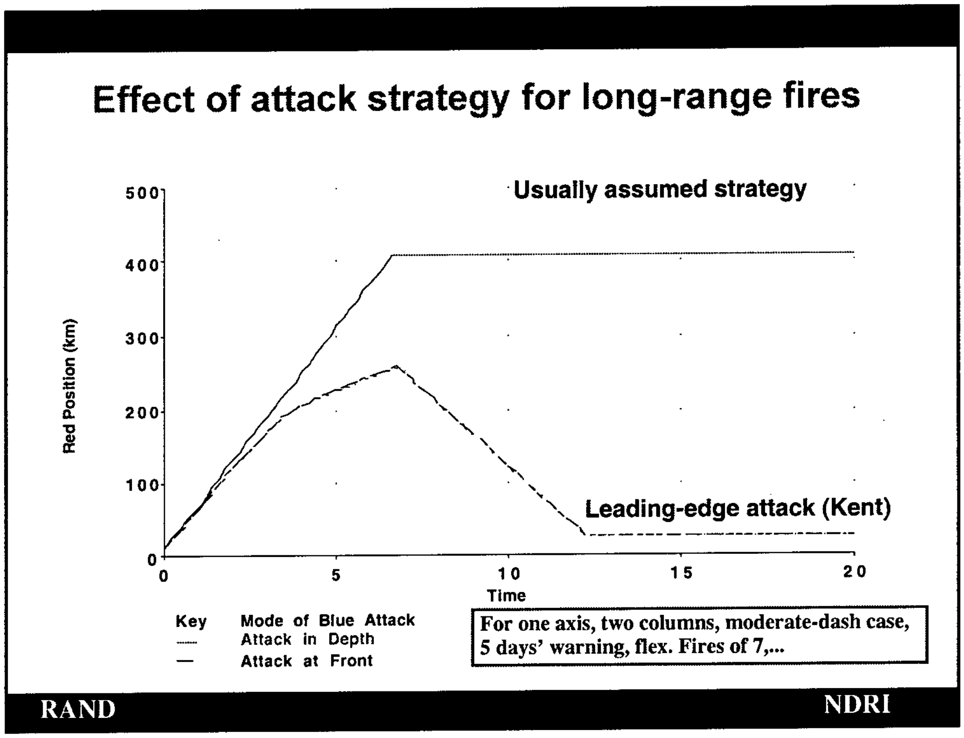
For exploratory analysis at a moderate level of resolution, we implemented a multiresolution version of our halt-phase model in the Analytica™ modeling system (Bigelow, Davis, and McEver [1998b]). A top-level view looks on the computer screen like this slide, which depicts the relevant processes at any slice in simulated time. During a given time period, Blue's forces are updated to reflect deployment and losses to air defenses (left side). Blue then runs a command-and-control process (top), which determines how its "shooters" will be employed. This decision depends on estimates of shooter effectiveness (bottom). After the decisions are made, Blue forces are employed at a level of effectiveness that depends on many factors (to be discussed). Blue suffers further losses during the time period, but Blue forces cause attrition to Red ground forces and may reduce their movement rate. Finally (right side), Red's force and position status are updated to reflect those losses and that movement.

To see more details while working at a Macintosh or PC, we can double click on the Blue Effectiveness module to bring up what appears on the next slide.



The module dictating the effectiveness of Blue shooters has many components, most of which combine to generate an ultimate effectiveness (top) measured in kills per shooter-day, separately for each type of shooter. On the top right we see nominal sortie rates, shooting rates, and kills per sortie or shot. These are the baseline inputs typically used in theater-level work or in simple spreadsheet models based on allegedly typical values. The other factors are all treated as corrections; in some cases, they turn out to be multipliers such as 1/2, 1/3, or even 1/10. Each of these factors is itself modeled (not shown here) as a function of some more-detailed variables. The result is a nearly hierarchical multiresolution modeling (MRM) construct: We can use the model to directly specify any of the variables indicated or we can generate the values of those variables in terms of still-more-detailed variables. The advantages of this approach can be dramatic because it permits analysis at alternative levels of resolution with the same model (Davis and Bigelow, 1998).

Nearly all of the factors adjusting shooter effectiveness depend, directly or indirectly, on command-and-control issues. We touch on only some of the factors here, but emphasize that developing this kind of framework is essential for analysis. The first factor is the effect of attack strategy (left side, within loop).



Force-employment assumptions that are often deeply buried in models can have an enormous effect on calculated outcomes. From our study of the attack-strategy model for a particular scenario, we present how far a simulated adversary might penetrate both if the defensive fires were applied throughout the depth of the attack (top curve) and exclusively to the leading edge, or nose, of the advancing column(s) (bottom curve). The latter strategy is dramatically superior, making it possible for a relatively small initial force to achieve a halt and even begin a rollback.[25] As our work shows, in other cases (e.g., with multiple axes of advance and multiple columns in each axis), the leading-edge strategy has no particular advantage and can be worse than the usual strategy, depending on details of assumptions about air defenses, command and control, and other factors.

The most important point here is that standard DoD-level models typically assume that a halt is achieved only after a big fraction of the attacker's force is destroyed (e.g., 50 percent), which would require a large force of shooters. However, in some important cases, even a small force using the leading-edge strategy could bring about a halt (and perhaps a rollback), even if the invader's morale were high, and certainly if it were not. Unfortunately, little is known empirically about whether leading-edge attacks of the sort postulated are feasible and as efficient as assumed in this calculation. Significant issues involving command-control in congested areas, interaction of strategy with air-defense effectiveness, what kinds of marches can be accomplished by second-rate armies, and so on, must be explored before a judgment of feasibility can be made. This suggests the need for *experiments* of various types, not just simulations. Similarly, experiments are needed to assess countermeasures. That is, tests, not just models, are needed.

[25] This strategy was conceived by colleague Glenn Kent and is described more fully in Ochmanek, Harshberger, Thaler, and Kent (1998). The model used in the current work is a synthesis of the basic Ochmanek et al. model, an earlier one developed in this project, and a variety of enhancements.

Example: Gain-Competence Factor

- **Effectiveness likely to rise with time:**
  - Team synchronizaton
  - Tactics for C4ISR assets, use of feedback,...
- **Standard approach in science: assume "learning time"**
  - Exponential approach to full effectiveness
  - Starting time? (C-Day, D-Day, strategic warning?)
  - Time should depend on readiness, training, threat size...
- **Analysis can show significance parametrically**
- **But times must be measured empirically**

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As our second example, consider the "gain-competence" factor (second from left within loop on the earlier slide of effectiveness decomposition). Our hypothesis is that the ability of Blue to command and control its shooters is likely to be lower early in the war than after the actual team of people involved in operations have prepared and gained experience. Effectiveness would also probably worsen in a many-versus-many situation because of command-and-control systems or their operators being saturated.

As is commonly done in experimental science when an effect is postulated or observed, but not yet understood, we describe the gain-competence factor analytically by assuming an exponential approach to full competence over time. The time constant is assumed to be a simple function of numbers of targets and shooters, and of the quality of the command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR) system. The baseline competence and the time constant must be determined experimentally, but we can vary them parametrically to characterize their potential significance.

In this way, analysis can identify priorities for follow-up work. It is in providing such broad views and in priority-setting that low-resolution and moderate-resolution exploratory analyses have great benefit.

Early Capabilities

Early Forces in Place

Forward-deployed Forces	Tactical Warning Time	Strategic Warning Time	Result: Force in Place
[illegible]	2 days	2 days	Good
[illegible]	2 days	[illegible]	Good
[illegible]	[illegible] days	[illegible]	Good
Inadequate	2 days	2 days	Bad
Inadequate	2 days	[illegible] days	Fair
Inadequate	[illegible]	[illegible]	Good

Ability to Fly Early

SEAD Time	Use of Stealth	Result: Ability to fly early
[illegible] days	[illegible]	[illegible]
[illegible] days	Some	[illegible]
6 days	[illegible]	[illegible]
6 days	Some	Bad

Early C4ISR Effectiveness

Competence Time From Warning	Strategic Warning Time	Early C4ISR Assets	Result: Early C4ISR Effectiveness
[illegible] days	2 days	Not survivable	Fair
[illegible] days	2 days	Survivable	Fair
[illegible] days	[illegible] days	Not survivable	Good
[illegible] days	[illegible] days	Survivable	Very Good
10 days	2 days	Not survivable	Bad
10 days	2 days	Survivable	Bad
10 days	[illegible]	Not survivable	Fair
10 days	[illegible]	Survivable	Fair

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There are many ways to display results of related analysis. To reinforce an earlier theme, we reiterate that the ability to achieve an early halt is very much a *system problem.* It is not enough to have some parts of the overall defense force working effectively with top-quality sensors, platforms, and weapons. Instead, any of a number of factors can greatly reduce overall effectiveness. That is, Blue needs shooters in place, good command and control and RSTA, effective weapons, and the ability to use all of these early—even in the presence of air defenses. Again, the requirement is for *all* of these.

This slide (see Bigelow, Davis, and McEver [1998]) illustrates this system aspect by displaying results of a moderate-resolution exploration across combinations of forward-deployed forces, tactical warning time, strategic warning time, the stealthiness of aircraft, the gain-competence time referred to above, and the early survivability (before SEAD is complete) of C^4ISR assets. In each of the three tables, the rightmost column is the result of the factors in the columns to the left of it. We see, in the center row of the lower table, that to have "very good" early C^4ISR effectiveness, we need to gain competence quickly (e.g., 4 days from strategic warning), to have and use 8 days of such warning, *and* to have the C^4ISR assets survivable early.

Outcomes for Different "Early-Kill Capabilities"
—Need *Combination* of Capabilities—

Small Red Force (500 AFVs to kill, 100 km Objective)

Force In Place	G	G	F	B	F	B	G	F	B	G	F	B	G	G	F	F	G	B	B	F	B	G	[illegible]	B
Ability to Fly Early	G	B	G	G	B	B	G	G	G	G	G	G	B	G	B	G	B	B	G	B	B	B	B	B
Early C4ISR Effectiveness	VG	VG	VG	VG	VG	VG	G	G	G	F	F	F	G	B	G	B	F	G	B	F	F	B	B	B
Result Red Distance (km)	47	47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	201	257	284	285	286	297	312	326	339	424	451	453

| <100 | [illegible] | >200 |

Large Red Force (4000 AFVs to kill, 300 km Objective)

Force In Place	G	F	B	G	G	G	F	F	B	F	B	B	G	G	F	F	B	B	G	F	B	G	F	B
Ability to Fly Early	G	G	G	G	B	G	B	G	B	G	G	G	B	B	B	B	B	B	G	G	G	B	B	B
Early C4ISR Effectiveness	VG	VG	VG	G	VG	F	VG	G	VG	F	G	F	G	F	G	F	G	F	B	B	B	B	B	B
Result Red Distance (km)	114	164	199	280	290	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	501	521	534	557	558	573	591	614	644	711	725	739

| <300 | [illegible] | >500 |

VG= Very Good; G=Good; F=Fair; B= Bad; VB= Very Bad

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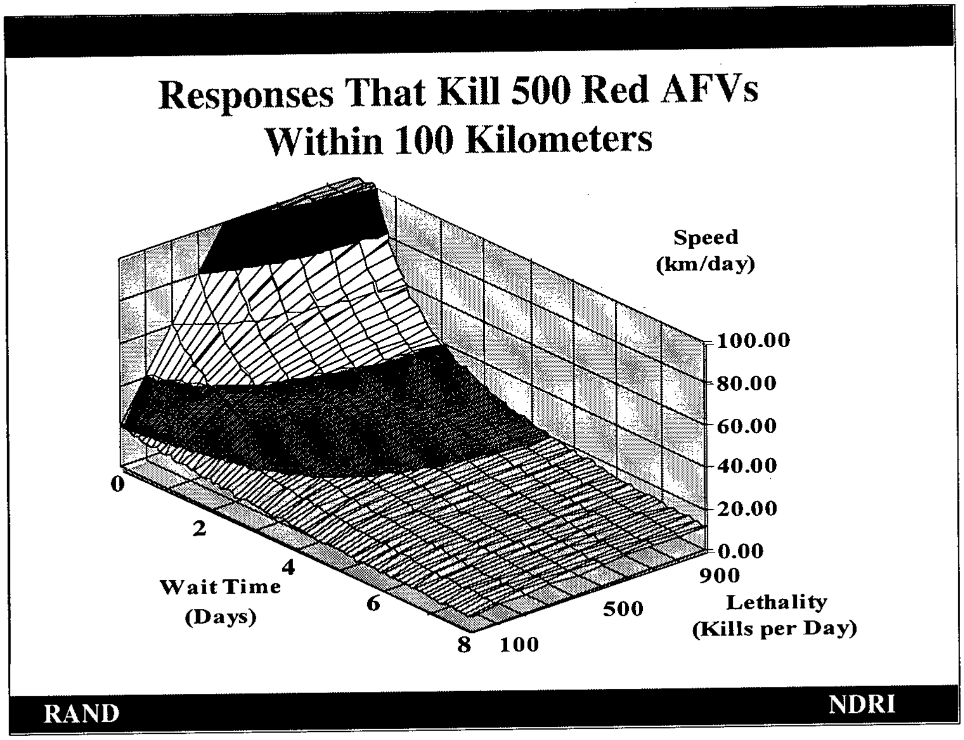
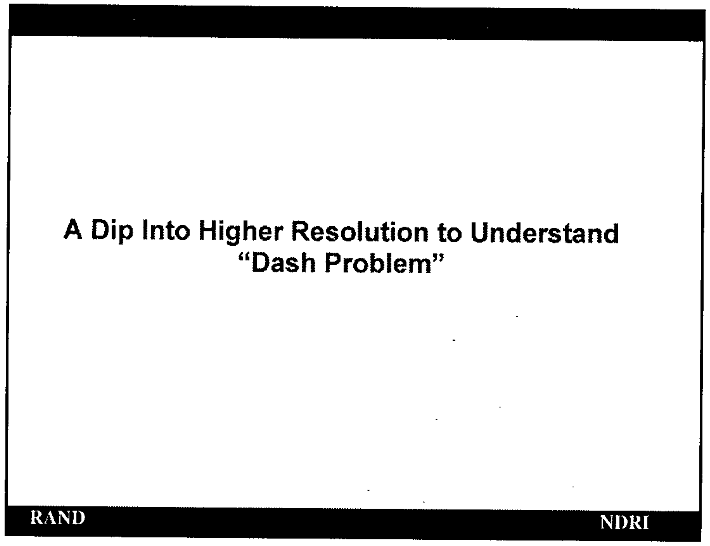
This slide summarizes a larger exploration at moderate levels of resolution. Here, each *column* is a case. The independent variables are the top three rows; the bottom row shows outcome. For the purposes of this display, an "early" halt is considered to be at distances of 100 km or less for a small threat (or one that "breaks" at a relatively low attrition level) (top), and at distances of 300 km or less for a larger or more-competent threat (bottom). The former would mean achieving a halt in Kuwait; the latter would mean the halt occurred in Kuwait or northern Saudi Arabia—well short of the major oil installations or capital. Any such analysis depends on a number of other assumptions being held constant. Our point is simply that exploratory analysis can generate a good synoptic description of early-halt capability versus a great many situational variables. Further, it can highlight system issues.

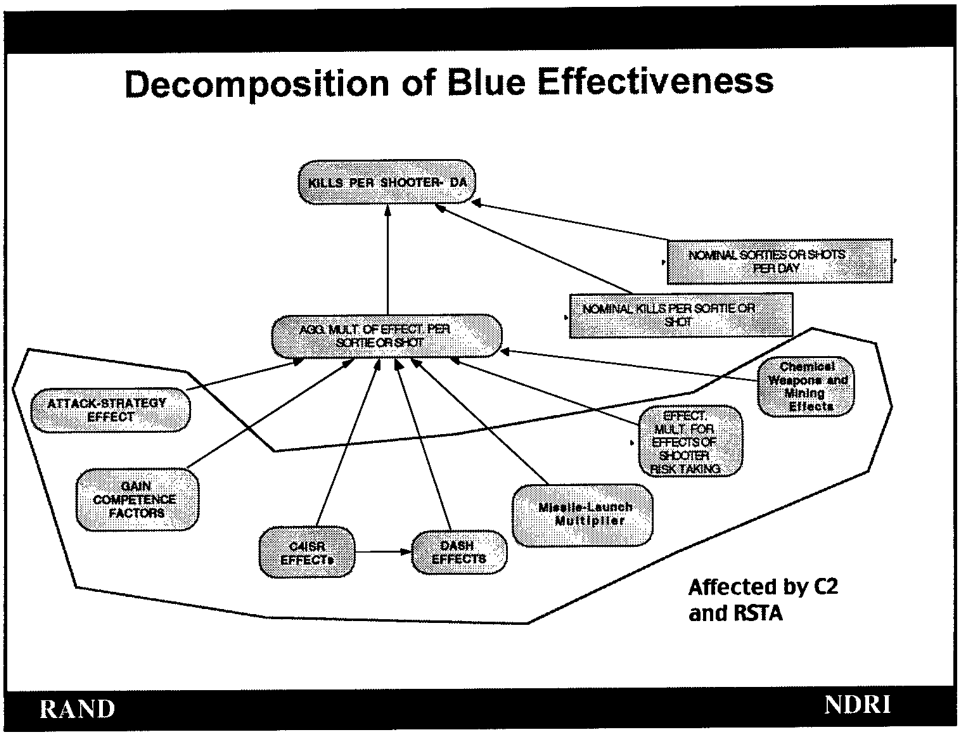


As a last display of exploratory analysis, this slide is a requirements plot (consistent with a subset of the previous slide), which shows what combinations of attacker speed, wait time, and defender lethality would bring about an early halt of a small or easily broken force. Combinations below the surface are successful; those above are not. The steep slope as one moves toward 0 on the wait-time axis (*wait time* is the larger of SEAD time or gain-competence time) or up the speed axis show how important it is to slow the enemy's movement rate and to begin operations almost immediately, rather than waiting either for a lengthy SEAD campaign or the buildup of command-and-control competence.

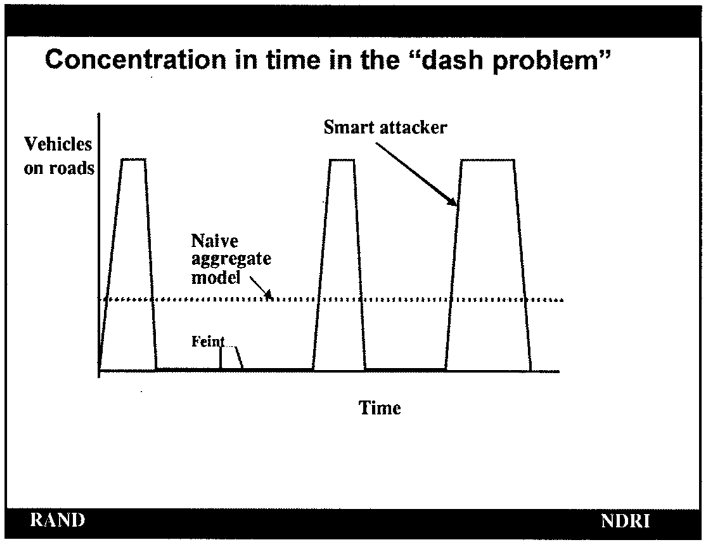
Just a few slides cannot present a respectable version of the overall exploratory analysis. However, the slides indicate the nature of the information sought and some of the many forms in which it can be presented. Further, they may have been sufficient to motivate more in-depth study of how to control the key factors better for the U.S. advantage.



Let us now illustrate the kind of information that can be obtained with higher-resolution analysis.



We repeat the Blue effectiveness-decomposition slide here to look at a fourth effectiveness factor—the dash effect, which reduces per-sortie or per-shot effectiveness.



In highly or moderately aggregated work, what we postulate and call the "dash factor" is ignored or, at most, is just a multiplier of effectiveness. But how do we understand what its magnitude might be?

Consider that the usual conceptual halt model—reflected even in theater models, which are often thought of as detailed—assumes that the attacker is moving down the roads at a uniform rate 24 hours a day, that the defender mounts sorties or missile shots at a uniform rate 24 hours a day, and that the resulting armor kills are determined merely by the product of, e.g., sorties per day and kills per sortie. To be sure, the mathematics does not really assume such uniformity, because sorties per day and kills per sortie are to be interpreted as averages over time of something potentially more complex. However, people usually have in mind something simple and uniform.

As this slide suggests, however, the attacker might not move in such a fashion. Instead, his forces might be on the road only episodically, for short periods of time. Considering that units can move, say, 30 km per *hour* when on the road, and that the overall daily road march is expected to be on the order of only twice that (60 km per day), it follows that actual movement time for a given unit is a small fraction of the day. It is at least plausible that—if hiding places were available en route—an entire army might move in such a fashion as to present moving targets only a fraction of the time (as low as 10 percent of the time). If, however, the defender's sorties were scheduled in advance, without knowledge of when the dashes would occur, then by far the majority of the sorties would be wasted. *It follows that there is a potentially catastrophic degradation of effectiveness for Blue's air forces because of Red's concentration in time.* The problem is likely much less severe in the open desert than in other circumstances, but it cannot be ignored—even for deserts—because of the possibilities of camouflage and other factors.[26] Whether such tactics are feasible for second-class armies is unclear.

[26] The first speculations about this problem were expressed in Davis and Carrillo (1997).

Need Higher-Res "Game" To Understand Problem and Calibrate Aggregate Model

- Entity level
- Attacker chooses concentration tactics (time and space)
- Defender can choose loiter, strip-alert and weapon-mix tactics
- Stochastic treatment of repair, turnaround time, etc. for air forces...
- Constraints: macro factors consistent with low-res model (e.g., on max daily speed, sortie rates versus loiter, limits on adaptation...)
- Result: insights on "game result"
- Inputs to low-res model: probability distribution, not single-value

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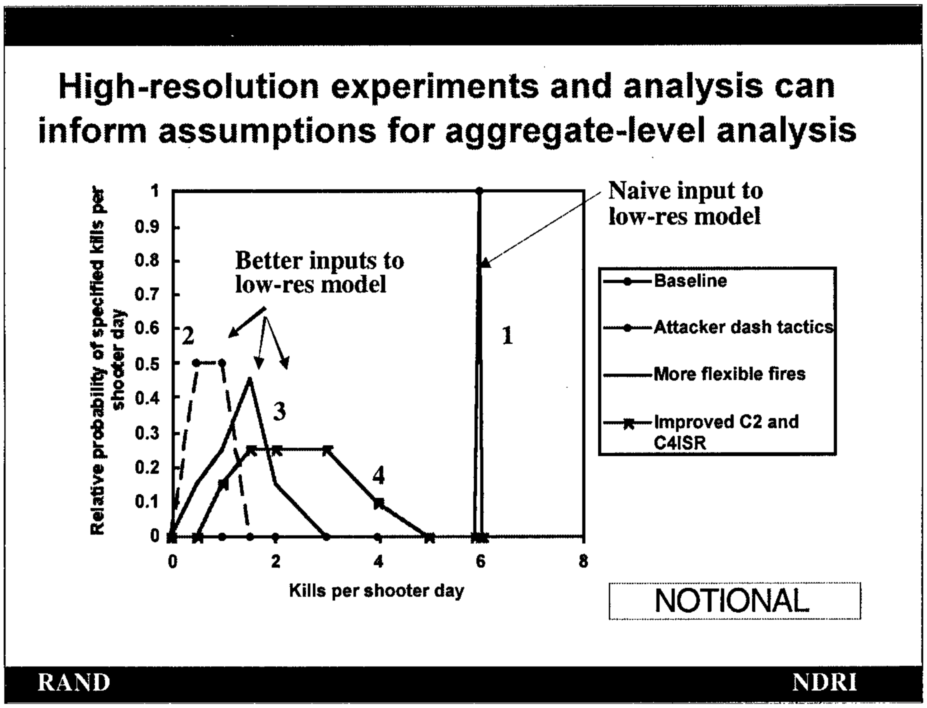
This problem is complicated when we consider measures and countermeasures. Blue, for example, could respond by maintaining some aircraft in combat-air-patrol (CAP) stations or on strip alert. Blue might arm sorties with a mix of munitions for moving and stationary targets. Blue's RSTA and command-control might use moving-target information to note where units "disappear" and, hence, where Blue should look for stationary targets with other sensors. But all such counter-countermeasures to the dash have further counters. Moreover, there are constraints such as the finite number of weapons that an aircraft or missile can carry, the finite number of hiding locations in any given theater, and so on.[27] Thus, generic parametric analysis can only take us so far. To understand what is really possible requires higher-resolution analysis, some of it scenario-specific.

[27] We thank colleagues Glenn Kent, Richard Hillestad, and Farhad Zaerpoor for discussions of this problem and the measure-countermeasure possibilities.



We have been working on such a narrow-scope high-resolution analysis but have not completed it. This slide is a *notional* representation of how, given a high-resolution model of the very narrow and, therefore, relatively simple dash problem, we would hope to use the high-resolution analysis to calibrate the models used for exploratory analysis. On the right (labeled "1"), we see what might be a naïve input to an aggregate model that ignores the dash effect. For example, if aircraft fly two sorties per day and kill 3 vehicles per sortie, then the aggregate model's input would be 6 kills per aircraft-day. However, if we did higher-resolution exploratory analysis within the limited domain of the dash effect, we might find that the effectiveness would vary widely according to the details of the circumstances, and that a stochastic representation would be more suitable.

The uncertainty distributions labeled "2," "3," and "4" might represent notional outcome probability distributions from exploratory analysis for sets of cases in which, respectively, (2) Red uses dash tactics, and Blue does not respond effectively, (3) Red uses dash tactics, but Blue responds with "flexible fires" (e.g., CAP stations and strip alerts), and (4) Red uses dash tactics, but Blue responds not only with more-flexible fires but also with more-effective command and control and RSTA (e.g., a mix of sensors able to locate and target both moving and stationary targets and an ability to use the best available shooters at any given time). For each of these sets of cases, the appropriate input to an aggregate model using the parameter kills per shooter-day would be a probability distribution with a large variance.

Dip Into Detail On Effects of Terrain, Force Structure,...

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As our final example of how high-resolution and low-resolution models can be used together—and need to be used together—we draw on work done by colleagues for the Defense Science Board, with guidance that had this project strongly in mind.

This dip into high resolution focuses on the interactions of terrain, force structure, tactics, and weapon characteristics. It may not be particularly relevant to the Persian Gulf's deserts, but it is quite relevant in other theaters. As a baseline, earlier work suggests that modern long-range fires might achieve on the order of several kills per sortie or tactical-missile-system (TACMS) shot against traditional armored columns in the desert with somewhat greater-than-usual vehicle spacing (100 m).[28] Our impression is that, before the work described here, most people expected an effectiveness for mixed terrain akin to that in, say, eastern Poland, or Virginia would be lower (e.g., perhaps a factor of 2), but not drastically so.[29]

[28] See, e.g., Matsumura, Steeb, et al. (forthcoming), DSB (1996b), and Ochmanek et al. (1998).

[29] Perhaps some Army and Marine officers expected something less because of personal experiences operating in mixed terrain, but it is our impression that their intuitive views have not been adequately appreciated by enthusiasts of long-range precision fires.

Misconceptions On Long-Range PGMs in Mixed Terrain

- Roads are open areas
  - Or, if not, successive open areas will be good detection and killing zones
- Detecting any part of a column is enough to project when *some* part of column will be at subsequent open areas
  - Reducing significance of time of flight, decision delay, etc.
- Arriving weapons that detect targets in open areas will kill them
- Large-footprint weapons compensate adequately for prediction error, albeit with price tag
- Currently on-track brilliant weapons are at least smart
- If all else fails, “excess” fire will ensure kills
- Counter-countermeasures will come along as fast as countermeasures for the post-2010 era

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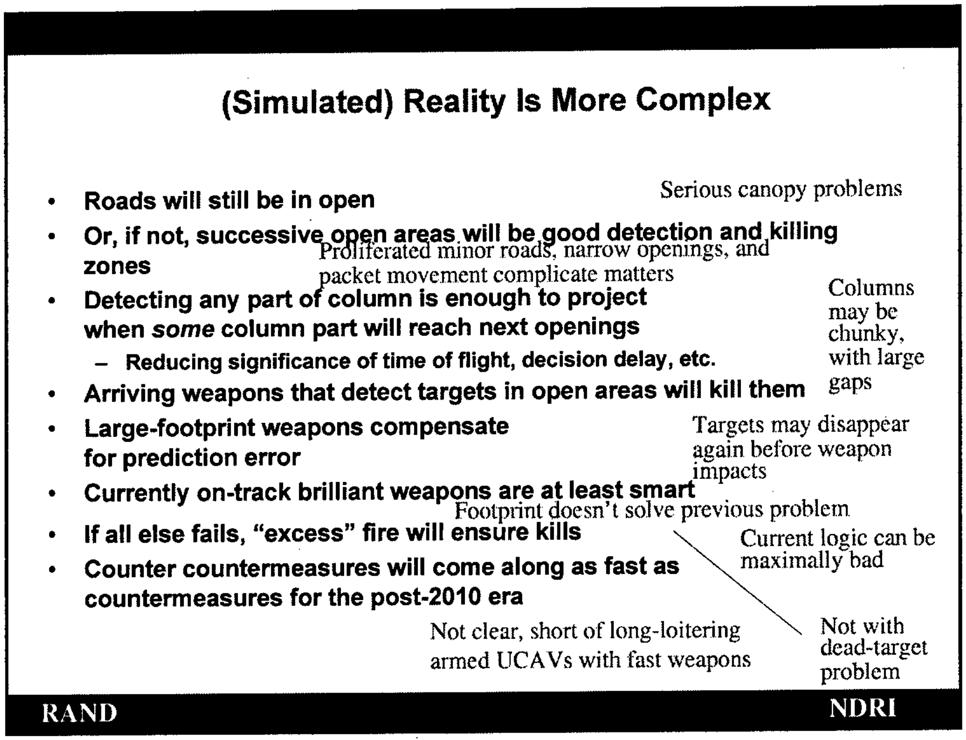
The entity-level simulation generated a number of surprises.[30] This slide reviews common beliefs held explicitly or implicitly by many members of the Defense Science Board task force. Roads, for example, are usually seen as broad, open areas—in part because the largest of American superhighways are open. Even when roads are more canopied—as is common in many mixed-terrain settings—there are various open intersections, which, intuition might say, would be ideal places on which to focus fires.

Implicit here and in much published analysis is a notion of rather uniform movement of the enemy columns. That is, a very long column of armored fighting vehicles (AFVs) and support vehicles moves like a snake down the road. In this image, it would not matter whether the weapons striking a target area hit vehicles, causing them to be dispatched in the first place. So long as a *density* of targets were moving through the open, the weapons would kill something. As a result, accurate en route tracking of individual vehicles would not be needed. Also, from work for the 1996 DSB Summer Study, it was known that—in open terrain at last—large-footprint weapons *or* mid-flight updates *or* hovering weapon platforms could compensate for effects of imperfect target-location prediction.

By and large, then, terrain was expected to be troublesome, but not unduly so. Further, it was believed that additional RSTA, large-footprint weapons, and so on, would prove quite helpful.

[30] The following material is excerpted from Appendix J of DSB (1998a), prepared by the principal author in an effort to understand and explain the high-resolution results reported in Matsumura, Steeb, et al. (forthcoming), which also appear in DSB (1998b).

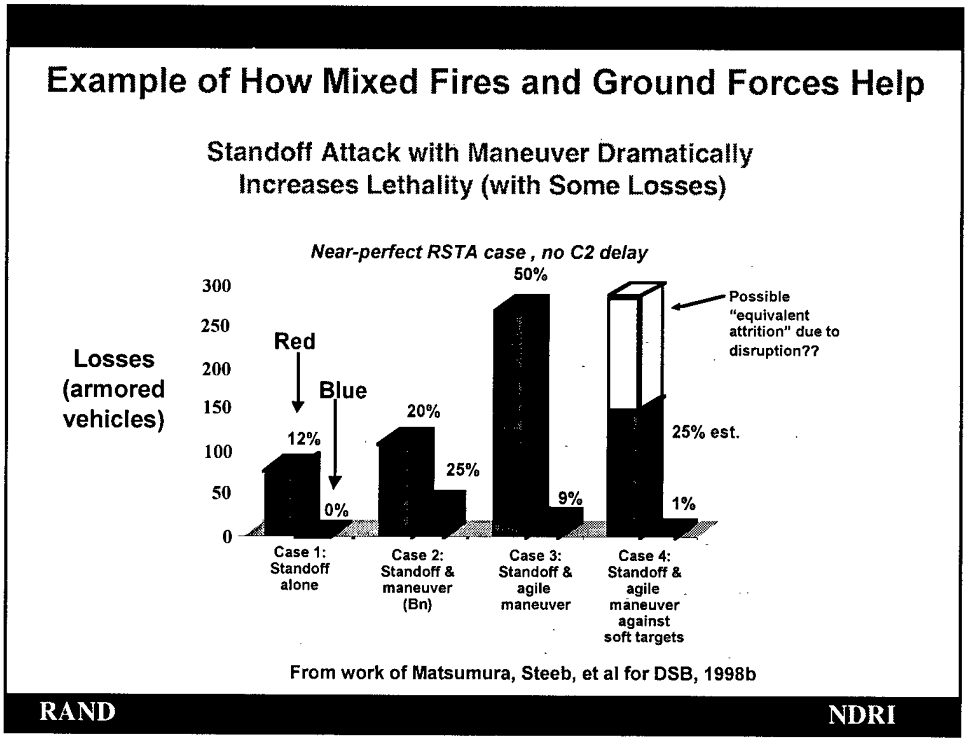


In retrospect, these assumptions were naïve. Many roads in a mixed-terrain theater are effectively canopied, because tall adjoining trees obstruct sensor line of sight. Second, having a sequence of open areas did not simplify the interdiction as much as expected. Columns could use any of several minor roads and, in this "intelligently scripted" simulation—simulations with submodels making human-like adaptive decisions—the attacker chose such roads wisely, which made prediction difficult, even with man-in-the-loop. Also, instead of moving in a single, long, uniform column, the responsive attacker moved in "packets": A platoon might move at roughly 70 km/hour with vehicles spaced at 50–100 m, but the next platoon might be 1–4 km back, and the distance between companies might be 2–8 km. As a result, being able to predict that some vehicles would get to an opening at approximately a particular time was not sufficient. If the error were large enough, the open space would be empty.

A rather surprising problem was that the time to cross an opening was sometimes roughly comparable to the time required for the terminal activity of an arriving weapon. Thus, an arriving weapon might detect and attack targets that would move again into foliage without being struck. Yet another frustrating result was that some "brilliant weapons" were not always so brilliant. Indeed, when tracks criss-cross, the simulation demonstrated that targeting logic can sometimes "anti-optimize" (i.e., the result can be to lay the weapons down ineffectively). Fortunately, such logic can be changed in software.

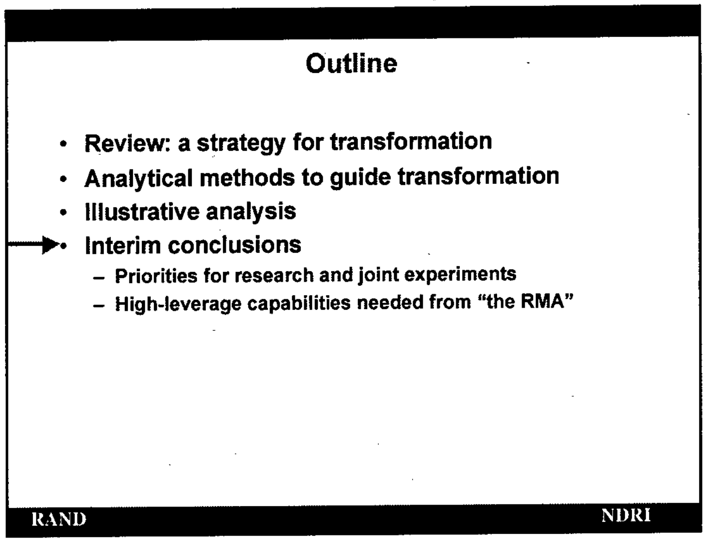
An obvious response might be to fire massively, with a disregard for efficiency. In the human-in-the-loop simulation, however, the human tried to avoid wasting weapons. Further, in some cases, there were sharply diminishing returns, because dead targets competed with live ones.

The net effect of this analysis was to suggest that currently technical programmed long-range fires may not be adequate in mixed terrain. It is not a matter of anticipating eventual countermeasures, but a matter of being realistic about likely tactics in the mid-term. Little of this was recognized in advance by those who work at a more aggregated level.



The high-resolution work also began the important effort to understand, with simulation, how small, mobile maneuver units could be used along with long-range fires in early offensive actions in mixed terrain against the invading army—even by deep operations. This summary slide shows how—at least for the scenario examined—the combination of such maneuver units used for ambushing and long-range fires (Cases 3 and 4) could be far more effective in causing attrition to and delaying Red forces than would long-range fires alone (Case 1) or long-range fires and a small unit (akin to an 82nd Airborne brigade with more-lethal weapons) inserted as a static blocking force (Case 2).

The analysis reflected many assumptions and depended on human decisions (made interactively by LTC Ernie Isensee, USA), as well as number crunching, but the insights seem valuable. In particular, the high-resolution results caused us to enrich our more-aggregated models. If that ongoing work is successful, we will be able to estimate the likely effects of many variables held constant in the high-resolution work. This iterative calibration and analysis can make multiresolution models or families more powerful.



4. Interim Conclusions

Let us now illustrate conclusions that can be obtained from analysis with a family of models, and how those conclusions can inform priorities for research. After that, we list some conclusions about what kinds of future capabilities appear to have the most leverage for the operational challenge of the halt problem.

Illustrative Conclusions for Halt Problem

From low-resolution exploratory analysis:

- Early halt (e.g., Kuwait) is feasible but very difficult
- Slowing enemy advance is critical: suggests allied packages and bottleneck creation
- Access problems are likely and can be disastrous
- High payoffs:
  - Forces in place and use of strategic warning (presence, arsenal ships and aircraft, Army missiles,...)
  - Quick SEAD or ability to operate during SEAD (e.g., UCAVS, HPM, standoff weapons)
  - High-end of plausible values of kills per sortie or shot (SFWs, BAT, good C^4ISR)
  - Leading-edge attack strategy

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On the basis of low-resolution exploratory analysis, we conclude that, in the Persian Gulf deserts, an early halt is feasible, but quite difficult to achieve. One requirement is slowing the enemy's rate of movement immediately, rather than after some days of a SEAD campaign. High-payoff capabilities would include high values of per-sortie or per-shot effectiveness, quick SEAD, the leading-edge attack strategy, and "ally packages" (discussed further below) that might contribute to the slowdown. Deployments after D-Day are less critical, because time is too short.

Another big factor is the *break point:* if the enemy is less determined and capable than is often assumed in studies, which seems likely, then the halt can be achieved much faster. Excessive conservatism (e.g., assuming highly determined and capable enemies) here is bad analysis and can bias judgments about the feasibility of strategies and the potential benefit of improvement measures.

Conclusions, cont'd

From moderate-resolution exploratory analysis informed by more in-depth research and modeling

- High payoffs from:
  - Flexible fires and related C^3 and RSTA adaptiveness
  - High D-Day competence in C^3 and RSTA
  - Stealthy or space-based C^3 and RSTA for early operations
  - Good weapons mix (large and smaller area, and single-target, versus movers and others)
  - Number of RSTA assets needed for success can be quite large

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From the somewhat higher-resolution exploratory analysis and more-microscopic reasoning that allowed for tactical countermeasures, we conclude that there are high potential payoffs from flexible fires, the type of fires that might be possible with loitering aircraft or unmanned combat air vehicles (UCAVs), strip-alert aircraft, and missiles; from ensuring high D-Day command-control competence; from having stealthy or space-based command and control and RSTA assets that could operate early; from weapon mixes that permit attacks on both moving and stationary targets; and from having adequate quantities of RSTA assets.

Conclusions (cont'd)

From high-resolution modeling and gaming of battle

- Estimates of system and weapon effectiveness for aggregate models
- Small units inserted into rear as "sensors" need significant organic capability
- Current JSOW may have very limited effectiveness in mixed terrain
- Usual emphasis on platforms and weapons, with command and control assumed, is seriously misleading
- Success depends on system of systems, not single bullet
- Long-range fires may be much less effective in mixed or rough terrain
- Mixed solution with fires and small maneuver units is attractive option to study
- Even "easiest problem" (stopping armor) isn't so easy

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From the high-resolution work, we can obtain reasonable estimates of real-world weapon effectiveness, although as uncertainty distributions rather than as point values. From earlier work, we know that small units used in rear areas may need significant organic capability for self-defense, even if allegedly protected by long-range fires.[31] The current joint standoff munition (JSOW) is very limited for use in mixed terrain. And we know that many of the issues are complex, involving the interaction of command and control, RSTA, terrain, weapon logic (including possible logic exploiting knowledge of roads), and the availability of in-flight updates.[32]

Significantly, there appears to be considerable synergy if long-range fires are used together with small maneuver units inserted behind enemy lines to attack in rear areas (when that is feasible). Again, we see that meeting the operational challenge is a *system problem.* In this instance, different components of the system can compensate for each other's limitations or failures.

The high-resolution results increase our humility by demonstrating that even the "easiest" problem for long-range fires—halting an invading armored force in the desert—is in fact not so easy, and certainly not in mixed terrain. One of our conclusions is that some of the capabilities usually thought to be "advanced" concepts for 10–20 years from now should instead be pursued more rapidly (e.g., in-flight updating of missiles' target information, loitering aircraft, UCAVs, and even missiles).

[31] Matsumura and Steeb (forthcoming) or DSB (1996b).

[32] Interesting high-resolution work demonstrating this interaction for the Korean peninsula will appear in a forthcoming RAND publication for the Air Force. The project has been led by colleague Ted Harshberger, who drew heavily on personnel and on models developed for use in work for the Army, as have we in this project.

Mapping Hypotheses to Methods

Hypothesis	"Simple" models	Campaign models	High-resolution models	Live / Virtual simulation (DIS)
Early-halt capability is highly cost effective	••••	••		
Fast SEAD OR intra-SEAD anti-armor attacks are key	••••	•••	•	
Allies' slowing enemy may be critical	••••	••		
Even "simple" campaigns are joint and complex		••••		
SEAD can be completed within 2 days	•	••	••••	••
C^2 will work well within 2 days of D-Day				••••
Enemy ground-force tactics could greatly reduce PGM effectiveness in SWA	•••	••	••••	••••
"Ally packages" could greatly reduce enemy speed			••	•••

RAND NDRI

Recall that the purpose of our analysis was not to "solve" the halt problem but, rather, to illustrate how analysis—with a mix of models and methods—could contribute to its understanding and, in the process, identify what empirical research is needed, including the joint experiments on which the Department of Defense is putting great emphasis.

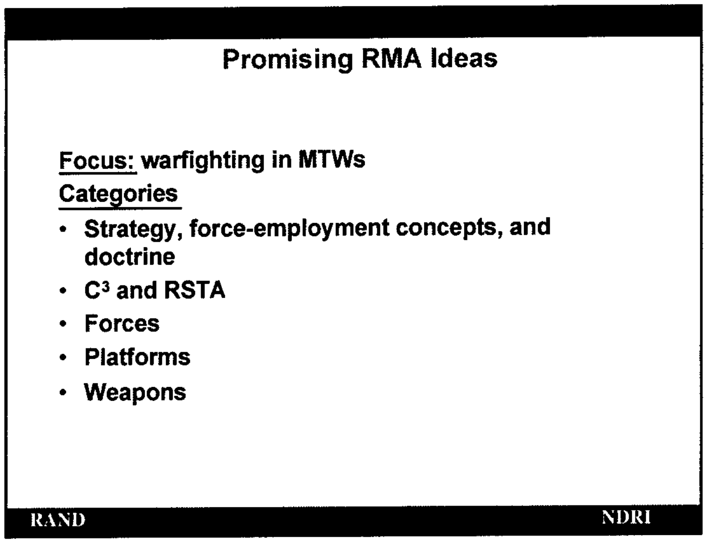
This slide, in which more bullets indicates more relevance of a model class to a particular hypothesis, suggests that many of the important hypotheses for study can be examined reasonably well with models and simulation—if backed up by good planning factors based on service-level experiments. In contrast, as indicated by the looped items at the bottom right, standard analytical modeling and simulation are inadequate for informing us about issues related to command and control, RSTA, rapid SEAD, the feasibility of various tactics, and the feasibility of quickly enhancing allied units that could help slow the enemy advance.

Experiments and Research Needed

- Realistic JTF-command-post exercises to measure C^2 and C^4ISR effectiveness versus
  - target/shooter load
  - nature of network
  - prior competence and gain-competence time, learning aids
  - doctrine,...
- Field experiments to measure real-world ability of sides to concentrate in time, vary tempos, etc.
- Rigorous research to establish all planning factors--as probability distributions for defined cases
- Also, joint experiments with live ground and air forces as dramatic demonstrations of PGM significance

RAND NDRI

A high priority should be set on empirical research dealing with the items shown in this slide. Again, the emphasis should probably be on higher-level matters involving human decisionmaking, command-and-control processes, and tactics in both joint and combined contexts. For the experiments to provide substantial value-added (beyond technology "demonstration"), some should be rigorous and many should be performed under stressful circumstances illuminating issues of risk and uncertainty. This, of course, is a major project theme.



Finally, let us summarize briefly what appear to be particularly promising "RMA ideas," based on the analysis to date. Some of these ideas will repeat material presented earlier in this documented briefing, but having such a list was of interest to our sponsors.

As this slide indicates, we focused on major theater wars (MTWs) and listed high-leverage potential under five categories.

Illustrative Concepts and Capabilities for MTWs

Strategy, force-employment, and doctrine

- Forward leaning in crisis
- Ally-enhancement strategy
- First-days employment of small lethal vanguard forces with lavish external fires and other support
- Maneuver and support from sea
- Early-interdiction for halt
- Attack of leading-edge forces
- Early offensive operations (even before halt) to "shatter" enemy

C^2 and C^4ISR

- Backbone for network-centric ops
- Virtual readiness-tuning for on-alert and deploying commands
- Survivable early-available high-endurance UAVs
- Continuous surveillance from space (MTI, SAR,...)
- Small ground forces as sensors and discriminators
- FOPEN radars
- Tactical-level UAVs, flying microsensors, UGS, ...

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At the level of strategy, force employment, and doctrine, a number of concepts and capabilities stand out. First, because of the warning problem and the potential for fast-moving invasions supported with attacks on ports and bases and by mining of SLOCs, our work suggests that national strategy should become rather aggressive in the sense of explicitly adopting a forward-leaning approach in the presence of strategic warning. This might include establishing quarantine zones to prevent mining, no-fly zones, red lines, and other boundary-setting measures to make surprise attacks difficult. Because of the importance of slowing the enemy, an ally-enhancement strategy is strongly suggested: Allied special forces on the ground, perhaps augmented and controlled in crisis by U.S. forces, could help create logjams and discourage fast movement.

Success in an early halt would be more feasible if the United States had a small lethal vanguard force for extremely rapid deployment with massive external fires, whether from missiles or aircraft. This was a conclusion upon which the 1998 DSB study also converged.[33] As discussed earlier in this documented briefing, preferentially attacking the leading edge of invading forces can have high leverage in many cases and, at least in some situations, so could early rear-area offensive operations by small units.

With respect to command and control and RSTA, an obvious conclusion from our review generally, but not our analysis specifically, is that developing the backbone for network-centric operations would provide desirable redundancy and adaptiveness. Because early command-and-control competence might be much less than desired, there would be value in refining training and "tune-up" exercises that could help the operators in a prospective operation work together virtually, even if not in the theater itself, from the outset of strategic warning.

[33] For a discussion of such a force, see Chapter 3 and Annex F of DSB (1998a).

Often not discussed is the need for RSTA systems that can operate and survive from the outset of war, even before SEAD is complete. Otherwise, an early halt will be very difficult to achieve if adversaries deploy long-range, survivable air defenses. Such systems might be accomplished with UAVs or space systems.

The other items on this slide go beyond what we have covered in the current briefing, but will be discussed in later work.

Illustrative candidates (cont'd)

Forces and Force Packages

- RDJTF vanguard: "brigade sized" with external fires
- Marine and AAN concepts (e.g., small teams, pods, ...)
- Network-centric layered theater missile defense (ABL, upper tier,...)
- "Ally packages" of communications, short-range PGMs, and liaisons

Platforms

- Stealthy high-sortie-rate medium- and long-range air forces
- Long-loiter fighters and bombers
- Arsenal aircraft and ships (or equivalent)
- Submerged "arsenal ships" and assault boats (SSGNs?)

Weapons

- UCAVs for SEAD and other selective attacks
- High-Powered Microwave SEAD weapons (HPM)
- Hypersonic standoff missiles
- Mid-course and terminal targeting updates for missiles and standoff weapons
- Inexpensive area munitions for infantry targets in rough terrain
- BAT for air forces
- Smaller PGMs to improve sortie productivity and UCAVS capability

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Turning to forces, platforms, and weapons, we again have quite a number of items that loom large. In many cases, analysis can merely indicate *potential* leverage. Extensive service-level and some joint research and experimentation will be essential to evaluate which of the candidates is feasible at an affordable price.

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